AMBIENT 2013

The Third International Conference on Ambient Computing, Applications, Services and Technologies

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AMBIENT 2013 Editors

Maarten Weyn, Artesis University College of Antwerp, Belgium

AMBIENT 2013

Foreword

The Third International Conference on Ambient Computing, Applications, Services and Technologies (AMBIENT 2013), held between September 29 and October 3, 2013 in Porto, Portugal, continued a series of events devoted to a global view on ambient computing, services, applications, technologies and their integration.

Towards a full digital society, ambient, sentient and ubiquitous paradigms lead the way. There is a need for behavioral changes for users to understand, accept, handle, and feel helped within the surrounding digital environments. Ambient comes as a digital storm bringing new facets of computing, services and applications. Smart phones and sentient offices, wearable devices, domotics, and ambient interfaces are only a few of such personalized aspects. The advent of social and mobile networks along with context-driven tracking and localization paved the way for ambient assisted living, intelligent homes, social games, and telemedicine.

We take here the opportunity to warmly thank all the members of the AMBIENT 2013 Technical Program Committee, as well as the numerous reviewers. The creation of such a broad and high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and efforts to contribute to AMBIENT 2013. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

Also, this event could not have been a reality without the support of many individuals, organizations, and sponsors. We are grateful to the members of the AMBIENT 2013 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope that AMBIENT 2013 was a successful international forum for the exchange of ideas and results between academia and industry and for the promotion of progress in the field of ambient computing, applications, services and technologies.

We are convinced that the participants found the event useful and communications very open. We hope that Porto, Portugal, provided a pleasant environment during the conference and everyone saved some time to enjoy the charm of the city.

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Expressing the Personality of an Intelligent Room through Ambient Output Modalities

Jean-Paul Sansonnet and Yacine Bellik
LIMSI-CNRS
BP 133, 91403 Orsay Cedex France
Email: {jps;bellik}@limsi.fr

***Abstract*—This paper deals with user friendly interfaces in ambient computing and its applications. In order to build more friendly ambient systems, some authors have proposed that the agent controlling the system should be provided with a mental model and should express personality traits and emotions "as if it were a person". Recent research in this domain is mainly based on the mediation of the ambient system by an animated virtual character, often endorsing the role of assistant. However, users can be distracted and side-tracked by such characters and even feel that they lose the control of the system. We explore here the feasibility of the direct expression of the emotional states and personality traits of the mental model of an ambient agent directly through the specific output physical modalities. First, we propose an alternative to the mediated architecture together with its specific agent model. Then, through two typical examples, we show how emotions and traits can be mapped onto ambient output modalities.**

Keywords — Personification, Ambient output modalities, Expression of emotions and traits.

I. INTRODUCTION

In this paper we rely on researchers that have claimed and showed that there is a usefulness of an intelligent environment to show psychological features such as emotions and traits. For example, in their 2005 survey on new technologies for ambient intelligence [1], Alcaniz and Rey discuss the impact of the implementation of psychological notions in future Intelligent User Interfaces (IUI): "The persona of an agent is the visible presence of the agent from the users perspective". The idea that an ambient should be perceived, hence reified as a personified agent, is currently growing. For example, Benyon has introduced the term 'personification technology', based on the notion of *anthropomorphism* [5].

In such ambient systems, we deal with three main entities: one or several human users; a physical environment capable of interacting with users through input/output modalities; a software agent controlling the physical environment and managing its interactions with users, hence called the ambient agent. In first ambient systems, the ambient agent was simply viewed as a global software controller. However, the need for more user friendly interface raises the issue of the relationships between the ambient agent and the users that is a) how the agent is presented to the users and b) how the users perceive the ambient agent. Two main strategies are:
— *Mediated personification*: the agent is represented by the introduction in the environment of a physical entity (a virtual character or a robot; being anthropomorphic or not) endorsing the role of the ambient system;
— *Direct personification*: the agent has no explicit physical presentation. Hence, it must be directly perceived and categorized through the output modalities of the system.

The advantage of mediated personification is that users are prompted to think that there is an intentional entity in the environment but they can fail to link it to the ambient agent (*e.g.*, considering it is another kind of user). The direct personification avoids this problem but raises another issue: how can we transfer the expression of psychological features of the ambient agent onto output modalities. In this paper, we explore a model of mapping emotions and personality traits upon the output modalities provided by an intelligent room.

The outline of the paper is as follows: In Section II, we present a short review of current research works dealing with the notion of personification. Section III describes our model for ambient personality, which implements two main notions: basic emotions and more complex personality traits. Section IV describes how actual output modalities of an intelligent room can be exploited to express the personality of a given ambient agent. Section V present a case-study upon the direct implementation of two psychological influence operators and shows their distinct impact on the execution of four actions in the ambient system. In Section VI, we open a discussion upon the propositions of Section IV and we sketch further lines of research stemming from this work.

II. RELATED WORKS

A. *Mediated personification*

According to Benyon [4], mediated personification technologies include on-screen avatars, robots and other autonomous systems imbued with character that demonstrate intelligence and affect, that know their 'owner' personally.

Indeed many authors are developing virtual graphical characters that can express human emotions. In the late decade, Conversational Assistant Agents (CAA) technologies [6] have produced some interesting results on factors such as *enticement*, *believability*, efficient *understanding* [21]. For example, in the IROOM project at CNRS [3], a virtual character interacts with users, as shown in Figure 1. However, Alcaniz and Rey note that several authors are opposed to agent based interface solutions and particularly to the personified type, claiming they remove user control and are distracting.

Among others, Nuttin et al. [20] have explored various interactional situations involving a robotic assistant agent for ambient environments. Note that in the particular case of a

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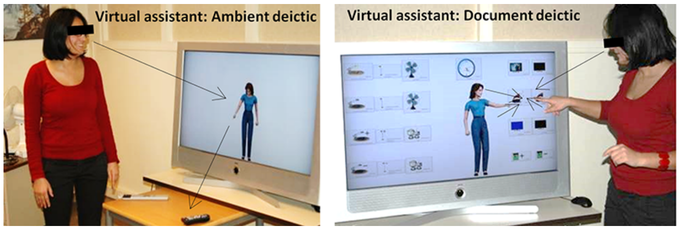

Fig. 1. Virtual assistant agent Elsi of the IROOM project. right) Elsi can explain (using text-to-speech) how ambient devices work through on-screen help; left) Elsi can find, point at and operate physical devices in ambient.

home room, they claim that "The domestic robot in this case, is a personification of the intelligent environment" on the basis that the robot is able to control the whole ambient, for example on behalf of users. Hence, the robot is supposed to be perceived by users *both* as a physical part of the ambient and also as the whole ambient. Indeed, it raises issues about users' cognitive representation of the ambient.

B. Direct personification

The difficulties with mediated personification have prompted a more direct method. For example, Richard [32] has proposed an approach to the personification of various kinds of data structures through the metaphor of "Subjectified personification as design strategy in visual communication", that is mainly seeing non human-like objects (*e.g.*, statistical data) as if they had human characteristics so that ordinary people can have a personal/immediate perception of them rather than logical/rational. Recently, a group of researchers have put forward the notion of Persuasive Feedback Systems (PFS), in the context of ambient environments. Persuasive systems aim at enticing people to modify their habits, not through authority exertion but through enticement and direct interaction with the system [25]. For example, Ko et al. [17] developed MugTree, that encourage people to drink water regularly and to keep a good water-drinking habit. Authors such as Fang and Hsu have showed in a survey [10] the positive influence of factors such as: attention calling (the way the system presents data meant to call attention to a user); aesthetic of the system; emotional engagement with the system. Also, systems have been developed to entice people to reduce their individual energetic consuming, for example by adding sparkling colored lights to the power cord of a device [13].

While the usage and the efficiency of virtual agents in order to personify ambient entities is still controversial, authors agree on the fact that ordinary people placed in an ambient environment, especially in small spaces, need to establish a personal and affective relationship (as in Affective Computing of Picard [23] or Computers As Social Actors of Nass et al. [19]) with the system as a whole.

III. A MODEL FOR AMBIENT PERSONALITY

A. Architecture

In this section, we describe the general architecture dedicated to the personification of an ambient agent. Here we only sketch its mains elements, focusing on the parts actually used in the Section IV. As stated above, two main strategies can used, involving either a mediated or a direct support of the personification of the ambient agent. These strategies are

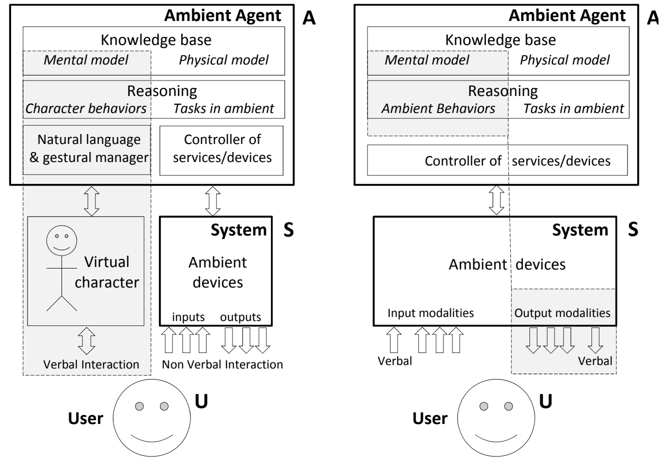

Fig. 2. Two main architectures for ambient agent personification. The personification process is enlightened in gray. Left) Mediated approach involving a virtual character; Right) Direct approach using ambient devices modalities.

illustrated in Figure 2 in order to facilitate their comparison. They share three main entities:
U: the User is an ordinary person who desires to use the ambient system.
S: the System is the physical part of the ambient environment.
A: the Agent is a software tool that endorses a role in a given ambient situation: helper, butler, partner *etc.*

In the mediated approach, personification is mainly supported through natural interaction with a virtual character. The management of the mental model of the ambient agent involves two specific modalities: dialog with the character in spoken language and expression of emotions and personality through gestural/facial animations of the virtual character. In this architecture, natural language is distinguished from devices input/output modalities; together with character animations, it prompts the user to categorize the character as an entity distinct from the ambient itself.

In the direct approach, personification is mainly supported through the modalities of the ambient devices. Note that input/output spoken natural language can be used but it is not a distinguished modality. The advantage of this architecture is that users are not distracted or side-tracked by the character. However, the direct approach raises the challenge of the feasibility of the expression of the mental model of the ambient while only using the output modalities of the ambient devices. In Section IV, we give two typical examples showing how such a mapping is possible.

B. Contribution of psychology on personality traits

Several theoretical domains pertaining to the personality of an individual have been developed over years: Freudian psychoanalysis; taxonomies of personality traits, Maslow and Rogers' humanistic psychology, Bandura's social-cognitive theory, *etc.* Among them, taxonomies of personality traits have been widely used as a ground for studies in affective computing [26] and cognitive agents [12]. This is the reason why we will rely on them in this study.

1) The Five Factor Model (FFM): Historically, traits taxonomies have been synthesized according to two main ap-

TABLE I. NEO PI-R FACETS FOR THE FFM PERSONALITY DOMAIN.

FFM traits	NEO PI-R 30 facets	Each facet is defined by a single gloss describing its +pole
Openness	Fantasy	receptivity to the inner world of imagination
	Aesthetics	appreciation of art and beauty
	Feelings	openness to inner feelings and emotions
	Actions	openness to new experiences on a practical level
	Ideas	intellectual curiosity
	Values	readiness to re-examine own values and those of authority
Conscientiousness	Competence	belief in own self efficacy
	Orderliness	personal organization
	Dutifulness	emphasis placed on importance of fulfilling moral obligations
	Achievement-striving	need for personal achievement and sense of direction
	Self-discipline	capacity to begin tasks and follow through to completion despite boredom or distractions
	Deliberation	tendency to think things through before acting or speaking
Extraversion	Warmth	interest in and friendliness towards others
	Gregariousness	preference for the company of others
	Assertiveness	social ascendancy and forcefulness of expression
	Activity	pace of living
	Excitement-seeking	need for environmental stimulation
	Positive-emotions	tendency to experience positive emotions
Agreability	Trust	belief in the sincerity and good intentions of others
	Straight-forwardness	frankness in expression
	Altruism	active concern for the welfare of others
	Compliance	response to interpersonal conflict
	Modesty	tendency to play down own achievements and be humble
	Tender-mindedness	attitude of sympathy for others
Neuroticism	Anxiety	level of free floating anxiety
	Angry-Hostility	tendency to experience anger and related states such as frustration and bitterness
	Depression	tendency to experience feelings of guilt, sadness, despondency and loneliness
	Self-consciousness	shyness or social anxiety
	Impulsiveness	tendency to act on cravings and urges rather than reining them in and delaying gratification
	Vulnerability	general susceptibility to stress

proaches: 1) Questionnaires to assess the personality of an individual (generally, yes/no questions) have been used by by Eysenck's Personality Questionnaires (EPQ) [9]; 2) Lexical resources use glosses of personality adjectives found in dictionaries. They have resulted in the FFM taxonomy [11]. When one is interested in the taxonomy of the psychological phenomena, especially those related to personality traits, FFM is the most prominent taxonomy in the context of computational studies [14]. FFM is composed of five main classes, listed in the first column of Table I).

2) The facets of FFM/NEO PI-R*:* The FFM taxonomy being a very generic classification, several authors have tried to refine this taxonomy by dividing its classes into so-called *facets* [7], [29], [31]. The number of facets can vary from 16 in [29] to 30 in the so-called NEO PI-R taxonomy (NEO PI-R stands for **N**euroticism **E**xtraversion **O**penness **P**ersonality **I**nventory-**R**evisited) proposed by Costa and McCrae [7]. In the FFM/NEO PI-R taxonomy, each facet is bipolar, *i.e.*, associated with a concept (pole +) and its antonym (pole-). The 30 bipolar facets of FFM/NEO PI-R are listed in the second column of Table I, together with their gloss. FFM/NEO PI-R is a long standing model that provides a very precise facet list, hence we will rely on it in this study.

TABLE II. TAXONOMY OF MENTAL STATES.

	Arity	
Dynamicity	Unary	Binary
Static	Trait Ψ_T	Role Ψ_R
Dynamic	Mood Ψ_m	Affect Ψ_a

C. Mental model

We only describe the content of the sub part of the symbolic structure that is associated with the agent psychology. Moreover, we define a specific mind model simple enough to support the examples presented in section IV. It covers most significant notions discussed in the literature about mental states modeling [22], with some simplifications (*e.g.*, we consider traits and roles are static during a session). This model distinguishes four types of mental states according to their *dynamicity* and to their *arity*, as shown in Table II.

Each of them is associated to a weight $w \in [-1, 1]$, where $[0, 1]$ denotes the intensity of the concept, $[-1, 0]$ is the intensity of the antonym of the concept and 0 the "neutral" position (neither the concept nor its antonym stand).

Traits (Ψ_T) correspond to typical personality attributes in FFM/NEO PI-R, considered as stable during the agent's lifetime.
Roles (Ψ_R) represent a static relationship between the agent and another entity in the ambient (typically the user). We define two main categories of roles:
— *Authority*: the right the agent feels to be directive toward the user and reciprocally to not accept directive behaviors from the user This role is often antisymmetric such as: Authority(X,Y) = -Authority(Y,X) where '-' denotes the antonym relation.
— *Familiarity*: the right the agent feels to use informal behaviors towards the user. This role is often symmetric.
Moods (Ψ_m) represent factors of an agent varying with time thanks to heuristics and biases, according to previous mental state of the agent and to the current state of the world. Moods are dynamic mental states that are often expressed through a set of simple emotions, as defined by Eckman [8].
Affects (Ψ_a) in this study, they will denote the dynamic relationships between the agent and the user. We distinguish at least three kinds of affects:
— *Dominance*: the agent feels powerful relatively to the user. It is often antisymmetric such as: Dominance(X,Y) = -Dominance(Y,X);
— *Cooperation*: the agent tends to be nice, caring and helpful with the user. It is not necessarily symmetric;
— *Trust*: the agent feels it can rely on the user. It is not necessarily symmetric.

IV. MODAL EXPRESSION OF AMBIENT PSYCHOLOGY

A. Assistant agents for ambient environments

In recent work at CNRS, we have implemented Conversational Assistant Agents in an ambient system [3]. Presently, in the IROOM project, agent/user interactions are supported by two main modalities:
— *Natural language* for control/command and assistance is based on Speech Recognition (SR) and Text to Speech (TTS).
— *Personification* is based on the display of virtual animated characters, on various kinds of screens, as illustrated by the ambient layout, shown in Figure 3.

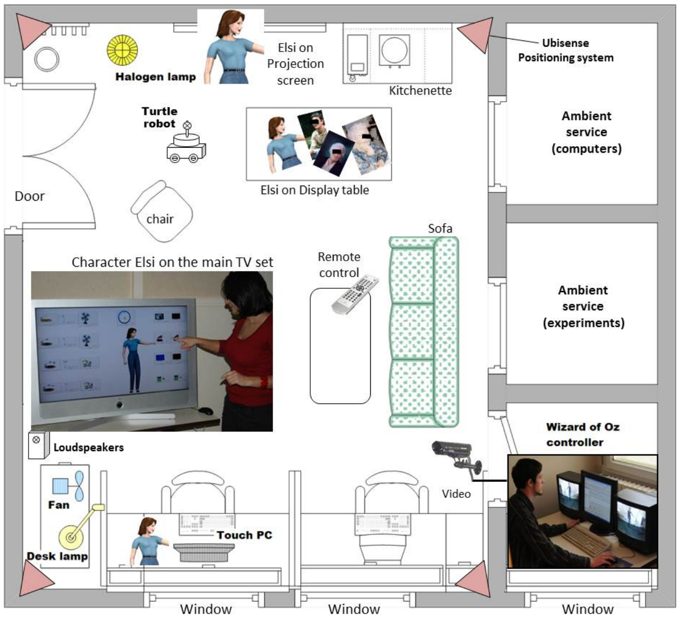

Fig. 3. Layout of LIMSI IROOM project.

Our main objective was to provide ambient systems with assistance capabilities exhibiting two main characteristics:
— *Rational assistance* is supported by an assistant agent about the control/command of the system;
— *Psychological behavior* associated with moods and traits, is performed by the agent in order to increase two important interactional factors: acceptability and naturalness.

However, the presence of a virtual agent on screen was interpreted by most users as the existence of an entity separated from the ambient system, hence prompting the user's mental scheme $\langle User, Ambient, Agent\rangle$. In this tripartite model, the agent is not viewed as consubstantial of the ambient system and this can lead to misunderstandings in user/agent interaction. This is especially serious in a situation where the user seeks help about the ambient that is already suffering from cognitive overload.
This is the reason why in this study, we propose a framework capable of prompting a bipartite user's mental scheme $\langle User, Ambientagent\rangle$. In this model, the user interacts **directly** with the ambient system "as if it were a person", hence called the $Ambientagent$, having the new requirements:
— *Natural language* in oral mode, becomes a prominent modality, though it remains globally unchanged;
— *Personification* is no longer supported by a virtual character;
— *Rational assistance* is unchanged;
— *Psychological behavior* is no longer expressed through virtual character modalities, hence it is necessary to find alternative modalities to express moods and traits.

In summary, the feasibility of such a direct mode of interaction relies on the possibility to express psychological behaviors in terms of ambient modalities, especially **output** modalities. In the following, we will focus upon the expression of moods and traits.

B. Expression of Ambientagent's moods

1) Ekman's basic emotions: As stated in Section III-C, moods are dynamic mental states that are often expressed

TABLE III. OUTPUT MODALITIES OF THE IROOM ENVIRONMENT.

Devices	*Activities*
Character display	*also used for information display*
Text to Speech	Agents' oral expression
Screens	TV, mural screen, touch PC *etc.*
Devices	*producing an output effect*
Air control	fan, heater, cooler*, scent dispenser*
Light control	lamps, electric curtains*
Sound control	music loudspeakers, alarms
Static appliances*	coffee-machine, cooker, fridge *etc.*
Robots	autonomous moving machines
Atmosphere	*main components*
Luminance	level, color (hot, cold, red, green…) and dynamics (waves, flash)
Music *(backgd)*	level and mood (chill, cheer, sad …)
Alarm	level, type and dynamics (bip, honk…)
Temperature*	level
Scent*	level and theme (spring, gas, sweat…)
Devices	force and specific action

*Not yet implemented.

through emotions, hence we restrict here to the expression of moods as emotions. Research on human psychology has developed several models of emotions. Typically, emotional states refer to Paul Ekman's six basic emotions [8] (see their list in Table IV-left) even if other authors, *e.g.*, Frijda, have proposed more advanced models.

2) Expression of Eckman's emotions through output modalities: In this case, we consider the output modalities of class atmosphere as in Table III. We fill one or more features (level, theme, type, *etc.*) in order to express Ekman's emotions. Table IV reveals two main results:
1. any atmosphere component is used, at least three times;
2. any emotion can rely on several modalities (at least three).
This shows that ambient output modalities can support the expression of basic emotions. Note that it does not imply that people would actually perceive and categorize them correctly.

C. Expression of Ambientagent's personality traits

1) The R&B framework: Previously, we have proposed a framework, called R&B (for Rational and Behavioral agents) [27], in order to express personality traits in terms of their psychological influences/alterations over the rational process of an artificial agent achieving a particular goal γ. This research is based on the principle of sub determination of plans: it states that for a goal γ, the planning module of a rational agent often produces several plans $\pi_i \in \Pi_\gamma$ that achieve γ. Typically a 'best' plan $\pi^\star$ is chosen in Π_γ by adding cost functions that rank π_i and sort Π_γ.

In the R&B framework, plan sub determination is preserved thus making it possible for Π_γ to be submitted to the influence of so-called psychological operators $\omega_i \in \Omega$. For example, the deliberation cycle of BDI agents [24], prompts a set Ω_{BDI} that can be partitioned into eight main classes: preference upon goals; preferences upon actions; norms and duty filtering; scheduling heuristics; modalities of action execution; optional actions; expectations (hopes, fears); appraisal of results of actions. (see [27] for a list of 30 operators associated with trait Conscientiousness).

2) Definition of a personality: Considering the FFM/NEO PI-R taxonomy, it is possible to define the personality $P(x)$ of a person x as a set of facets, activated in +/- mode. For

TABLE IV. EXPRESSION OF EKMAN'S EMOTIONAL STATES.

Mental states	Luminance	Music	Alarm	Temp.	Scent	Device
None	= neutral	= chill	0	=	0	= unspecific
Joy	+ hot	+ cheer	0	=	+ spring	+ Robot.move
Sadness	- cold	- sad	0	-	0	- Robot.move
Fear	+ red *blink*	0	+ danger *	+	+ gaz	+ Robot.hide
Surprise	+ neutral *flash*	0	+ oops 1	=	0	0 Robot.stop
Anger	+ red	+ harsh	+ rap *	+/-	+ sweat	+ Fan.run
Disgust	- Gloomygreen	0	0	-	0	= unspecific

*0 is none = is neutral + is higher than neutral or none (- is lower). 1 executed once; * denotes repetition.*

example, suppose Paul is lazy and easily stressed whereas Lucy is a hard-worker, trustful and modest. Their personality can be transcribed in FFM/NEO PI-R facets (see Table I):
$P(paul) = \{C_{-selfdiscipline}, N_{+vulnerability}\}$
$P(lucy) = \{C_{+selfdiscipline}, A_{+trust}, A_{+modest}\}$.

3) Example of operators of influence: Each facet in $P(x)$ activates a set of psychological operators $\omega_i \in \Omega$ that influence plans (and actions in plans) when they are performed by x. Among operators associated with FFM/NEO PI-R facet $C_{+selfdiscipline}$ an obvious one is $\omega_{hardworker}$, which is a hyponym of +pole definition: "capacity to begin tasks and follow through to completion despite boredom or distractions" (Table I) *resp.* ω_{lazy} is a hyponym of the -pole facet. We have extensively detailed how facets are linked to psychological operators in previous works [27] [28], but this discussion is beyond the scope of the paper.

V. CASE-STUDY

A. Implementation of influence operators

Considering the classes defined in Section IV-C1, we restrict for this example to two kinds of influences that are complementary:
1) *Plan alteration*: the $Ambientagent$ has the capability to avoid performing an action a_i part of a plan π either by providing the user with a dialogical Rebuke or by substituting a less-hard-to-perform Alternative action. Respectively, the $Ambientagent$ can add optional actions. For example: pleasant actions; cleaning-up *etc.* (Note that an optional action must not prevent a plan to achieve its goal).
2) *Action manners*: the $Ambientagent$ has the capability to perform an action a_i in a Partial manner or in a Slack manner. Respectively, actions can be executed in an Exceed manner (make more coffee than asked) or in an Efficient manner (*e.g.*, focused, precise, quick).

B. Example: a lazy vs hardworker ambient

As an example, we will contrast the actual behavior of an agent associated with operators of influence associated with the positive pole and respectively the negative pole of facet Self-discipline of trait Conscientiousness of the FFM/NEO PI-R taxonomy: operators ω_{lazy} and $\omega_{hardworker}$.
— Table V implements an ambient associated with operator ω_{lazy}. In column 1, are listed four examples of actions that can be performed by an ambient agent associated with the IROOM. For each action, two alterations (Rebuke, Alternative) and two manners (Partial , Slack) are used. For example, a "lazy ambient", when requested to open a room's curtain, will react by executing one or several influences described in Table

TABLE V. INFLUENCES OF ω_{lazy} UPON FOUR ACTIONS IN AMBIENT.

Ambient Actions	Rebuke[a]	Altern.	Partial	Slack
Open a curtain	too shiny!	lamp on	yes	yes
Play music	.[b]	.	yes	.
Set timeout	.	post it	.	.
Clean floor	bag full! battery low	.	yes	yes

[a] Rebukes are expressed in spoken modality (abridged here).
[b] no influence is applicable.

TABLE VI. INFLUENCES OF $\omega_{hardworker}$ UPON ACTIONS.

Actions	Pleasant	Clean-up	Exceed	Eff.
Open a curtain	add comment on weather	switch off lights	open other curtains	yes
Play music	choose joyful, add light...	class CDs	set sound very loud	.
Clean a floor	add scent, music, light...	clean tools (broom)	clean other floors	yes

V: saying "it is too shiny outside!"; propose to switch on a lamp; just open the curtain just a little and/or slowly.
— Table VI implements $\omega_{hardworker}$, using in this case two alterations (pleasant, Clean-up) and two manners (Exceed, Efficient). Hence, when asked to open a curtain, a "hardworker ambient" will react in a very different way. It will efficiently do: comment on the weather, switch off active lamps, and also open other curtains.

VI. DISCUSSION

Table IV reveals two main results: a) any atmosphere component is used, at least three times b) any emotion can rely on several modalities (at least three). This shows that ambient output modalities can support a form of expression for basic emotions (*resp.* for personality traits). Indeed, it does not imply that people would actually perceive the modalities and moreover, would correctly categorize expressed emotional states and personality traits. Further experiments with subjects placed in the IROOM environment are required. For example, one could experiment how user's profiles (sex, culture, age, *etc.*) influence the perception of ambient emotional states.

In this line, psychologists already have endeavored since the '70, a lot of research about the impact of ambient outputs upon people: Ambient temperature related with aggressive behavior [2] ; it has also been studied in conjunction with horn honking [15]. The influence of ambient odors on creativity, mood, and perceived health has been investigated by many authors since Knasko [16]. All these works bring a convergent positive pattern that people effectively perceive ambient physical output modalities and that their behaviors are altered by them. Hence, we think that there is a case for further investigating the direct personification hypothesis.

Moreover, people do not react uniquely to ambient modalities. This has been successfully addressed by psychologists working in the ambient context: Ethnic differences [30]; FFM model-based differences [18], *etc.* Actually, what people make of the cues sent by the environment entails a new area of research.

VII. Conclusion and future work

In this study, we have proposed a framework to express the emotional states and personality traits of an ambient environment directly through its output modalities, as an alternative to the mediation of the ambient by a virtual conversational agent. Our approach is based on three supports: 1) the well-used models for emotions (Ekman) and traits (FFM/NEO PI-R); 2) the R&B framework stating how psychological features can be implemented in terms of influence operators over the rational decision making process of artificial agents; 3) the experimental ambient environment (IROOM project at CNRS) providing a set of output modalities. We have shown the feasibility of the approach through an illustrative example. In future works, we are going to extend this framework to the handling of roles and affects and to carry out experiments, involving subjects in the IROOM, in order to assess to what extent users perceive the psychological expression of the $Ambientagent$.

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Analysis of Psychological Stress Factors and Facial Parts Effect on Intentional Facial Expressions

Kazuhito Sato
Department of Machine Intelligence and Systems Engineering,
Faculty of Systems Science and Technology, Akita Prefectural University
Yurihonjo, Japan
ksato@akita-pu.ac.jp

Hiroaki Otsu
Department of Machine Intelligence and Systems Engineering,
Faculty of Systems Science and Technology, Akita Prefectural University
Yurihonjo, Japan
m13a006@akita-pu.ac.jp

Hirokazu Madokoro
Department of Machine Intelligence and Systems Engineering,
Faculty of Systems Science and Technology, Akita Prefectural University
Yurihonjo, Japan
madokoro@akita-pu.ac.jp

Sakura Kadowaki
Smart Design Corp.

Akita City, Japan
sakura@smart-d.jp

Abstract—**This paper presents a gender-specific stress model to analyze the psychological stress factors on intentional facial expressions. We have focused on the relationship between facial expression intensity and Stress Response Scale (SRS-18). In this paper, we extract three facial expressions (i.e., happiness, anger, and sadness) from the basic six facial expressions defined by Ekman, and then represent a graphical model of the relationship between these three facial expressions and the psychological stress factors (i.e., "depression and anxiety", "displeasure and anger", and "lassitude"). In the experiment, we created an original facial expression dataset consisting of three facial expressions and a psychological stress dataset by SRS-18 obtained from 10 subjects during 7-20 weeks at one week interval. As the results of probabilistic reasoning based on the observed values of each facial expression, such trends were obtained as follows. BNs shows trends of different stress factor between men and women in relations of expression levels and psychological stress. Stress models appeared on happiness faces of "lassitude" factor in men, the anger faces of "displeasure and anger" were affected with stress factors in women.**

***Keywords-Bayesian networks；Expression levels；SRS-18；Intentional facial expressions*.**

I. INTRODUCTION

Modern society is full of stress. Numerous people live their lives with a variety of stressors. Stress is a biological reaction that develops when we confront a psychological or spiritual stressor [1]. Reactive processes of people interacting with the environment signify individual cognitive processes involved in biological reactions and physiological processes. There are three indexes of biological bodies, psychology, and action that demand the consideration of individual processes when subjected to stress. Usually, the human brain effectually responds to maintain mental and physical balance. However, excessive stress can trigger mental illness such as depression [1]. Because it can be difficult to conceal stress, faces are often called a window by which one can discern information of various types such as the modality of a person's mind, and health condition. Especially, facial expressions can show aspects of internal psychology, reflective emotions such as delight, anger, sorrow, pleasure, and the existence of stress. Close friends and family members communicate while interpreting stress from conditions and changes of facial expressions.

For this study, we specifically examine intentional facial expressions. Moreover, we set the upper part, lower part, and whole parts of the face as regions of interest (ROI) to address static and dynamic diversity, as defined by Akamatsu [2]. We quantify the relation between facial expressions and psychological stress by employing Bayesian networks (BNs), which can describe stochastic relations of events as a graphic structure. In our evaluation experiment, we create stress models by gender, and then analyze stress factors and stress elements in facial expressions of various types: happiness, anger, and sadness.

II. RELATED STUDIES

Existing methods for measuring stress are divisible into two types: a contacted type and a noncontact type. By using

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the findings that stress can affect amylase secretion in saliva, methods for quantifying stress have been proposed and many products are marketed based on the findings [3] [16]. In association with the autonomic nervous activity and stress, many analytical studies of the heart rate variability have been performed. At present, various devices have been developed and are used in research and clinical practice [4] [17]. There are many reports on the correlation between stress and neural activity of the cerebrum, In particular, Electroencephalography (EEG) is one of the indicators that have been studied for many years, researches using EEG have been performed on the context of the psychological state, such as attention and concentration, stress and anxiety [5] [18]. As a new functional brain analysis method, Near-infrared spectroscopy (NIRS) for measuring the cerebral blood volume changes locally non-invasively is also attracting attention as a stress measuring method, which indicates that the activity of the prefrontal cortex is changed significantly [19]. However, the objective comparison related to identify the most suitable approach for stress measurements is very complex, because each researcher has a different story, e.g., the type of stressor used in their experiments is different for each approach. In addition, these methods of contact type are susceptible to contact interface generally.

Stress measurement checking using a questionnaire form is a noncontact popular measurement method. The Profile of Mood States (POMS) [6] is an inventory that is recognized worldwide, although its results cannot generally be compared because the target attributes differ. POMS consist of 65 items. The brief version of POMS consists of 30 items [7]. POMS becomes extremely burdensome if we take images of facial expressions together. Suzuki et al. developed the Stress Response Scale-18 (SRS-18) [8], which is useful for a wide range of subject ages. SRS-18 comprises 18 items. SRS-18 measures psychological stress encountered over a short time. Moreover, SRS-18 shows highly discriminative capability in high stress and low stress groups. Numerous question items are available on SRS-18 related to an event that a normal person encounters daily while most existing stress evaluations are aimed at the assessment of clinical conditions. We regard SRS-18 as an optimal and helpful inventory to be used to assess facial expressions because of the measurement of physical and mental reactions and smaller number of question items.

III. Relations Of Psychological Stress And Facial Expressions

A suitable amount of stress improves activation and leads to work efficiency. However, excessive stress produces psychosomatic abnormalities because of humans' limited adaptive capability. How one feels stress effects is reported to vary delicately in similar environments because of individual differences from conditions and tolerance of stress [9].

Therefore, it is necessary to measure a state of stress in individuals. Furthermore, we must take steps to improve a bad stress state soon after it occurs [1]**.** Therefore, we must become able to grasp a person's emotional state considering corresponding relations to biology, psychology, and action for stressors of various kinds. The relations between the changing expression intensity and psychological stress with facial expressions can be verified from their psychological and behavioral aspects. We can assess expressions of individual facial expressions using Facial Expression Spatial Charts (FESCs) [10]. Our experiment results suggest the influence of psychological stress on facial expressions. For this study, we create a model of stress elements for individuals of both genders using BNs. Then, we graphically analyze the interdependence between psychological stress and facial expressions. For this study, we designate a parameter of expression intensity that quantitatively expresses facial expressions.

IV. Datasets

For this study, we constructed a dataset to assess facial expression changes. We measured the psychological stress of a subject showing facial expression changes by using SRS-18 and comparing the results to the facial expressions.

A. *Facial Expressions Images*

We set the term during which we measured facial expressions to construct individual models of stress elements. We constructed an original and long-term dataset for the specific facial expressions of one subject. For the experiment, we created original facial expression datasets from 10 subjects, with each dataset including images with three facial expressions: happiness, anger, and sadness obtained at one-week intervals during 7-20 weeks. The subjects were five women (Subjects A, B, C, and D were 19; Subject E was 21) and five men (Subjects F and J were 19; Subjects G, H, and I were 22), all of whom were university students. The order of facial expressions in a single measurement is in the order of happiness, anger, sadness. When taking images of each facial expression, the same expression is repeated 3 times on the basis of neutral facial expressions during the image-taking time of 20 seconds. We previously instructed subjects to express an emotion 3 times during the image-taking time. One set of data consisted of 200 frames with the sampling rate of 10 frames per second.

We set the Region of Interest (ROI) to 90 x 80 pixels, including the eyebrows, which all contribute to the impression of a whole face as facial feature components. We set the ROI of the upper part to 40 x 80 pixels including the eyebrows, which contribute to the impression of upper facial parts as facial feature components. We set the ROI of the lower part to 50 x 80 pixels including the mouth, which contributes to the impression of lower facial parts as facial feature components.

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B. Target Facial Expressions

We set three facial expressions of object facial expressions because the facial expressions are acquired over a long term for our study. We sought to reduce the load on subjects. We selected happiness, anger, and sadness from six basic facial expressions by Ekman [11]. He pointed out that Japanese people show disgust by smiling to conceal their true emotions. Therefore, we consider that it is difficult for subjects participating in this study to express disgust. The emotion of fear is a rare feeling in daily life. In the opinion of subjects, it was often stated that they are not aware of how they appear when feeling fear. Therefore, we do not record fear among the facial expressions. Surprise can readily occur along with fear, happiness, solace, anger, and despair [11]. Therefore, we do not include surprise among the recorded facial expressions because it invariably translates into complex facial expressions.

Our target facial expressions are therefore happiness, anger, and sadness, which include the geometry of each quadrant of Russell's circumplex model [12].

C. Stress Measurement

Psychological stress reactions are anxiety, anger, lassitude and difficulty in concentrating, which are encountered on a daily basis when one is affected by stressors. Our measurement contents are three robust stress factors: "depression and anxiety", "displeasure and anger", and "lassitude". Subjects respond on the check sheet along a four-response method for 18 items, answering with responses from "Completely different" to "It's correct". Each answer receives a score of 0-3. High point totals signify a higher degree of stress. Moreover, stress levels are represented by consultation value Level 1 (i.e., weak), Level 2 (i.e., normal), Level 3 (i.e., slightly strong), and Level 4 (i.e., strong). For this paper, we define the reported values as stress levels. For this experiment, we measured stress values using the SRS-18 and took facial expressions of 10 subjects. To avoid influencing the facial expressions, we reported no scores to subjects. Moreover, subjects wrote their responses to SRS-18 before recording facial expressions.

D. Extraction of Facial Expressive Intensity

Figure 1 shows a flow chart of our proposed method. Features are emphasized using Gabor wavelet filters as the preprocessing of input images. We reduce noise and constrict the amount of information using time-series images decorated with Gabor wavelets and processing coarse graining. We extract the topological variation of facial expressions and normalize constriction to the time direction using coarse graining data. Therefore, we classify images into patterns of facial expression categories depending on Self-Organizing Maps (SOMs) [13]. Moreover, we reclassify facial expressions images using SOMs and Fuzzy Adaptive Resonance Theory (ART) [14] of adaptive learning algorithm with stability and plasticity. SOMs set a mapping space by categorization of some items relative to others. However, Fuzzy ART can categorize same standards because it categorizes definite granularity using vigilance parameters. We rearrange the reclassification of categories based on neutral facial expressions. We consider that the categories show the influence of facial expressions.

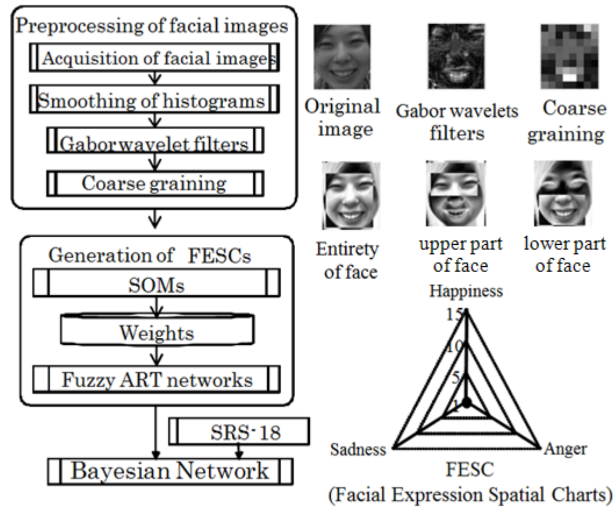

Figure 1. Procedure of the proposed method

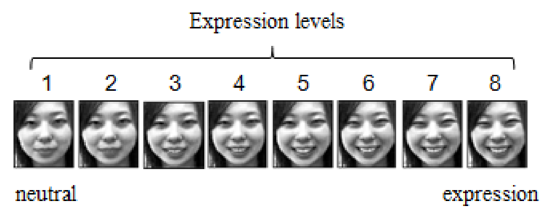

Figure 2. Expressive intensity

Figure 2 shows the expression intensity, which quantifies the strength of expression. SOMs of unsupervised learning are eminently useful for clustering and visualization. We classified facial expression patterns using SOMs to extract the facial expression topology. Fuzzy ART is an unsupervised learning neural network of incremental learning that can learn new patterns while maintaining past memories. Therefore, we regard ART as the optimal method for pattern learning of individual facial expressions. For our method, we reclassify facial expression images using Fuzzy ART in classification using SOMs. The pattern classification using SOMs categorize in set mapping space. Therefore, classification results are relative. However, we consider reclassification of constant granularity using Fuzzy ART as an extractive method to infer the individual expression intensity.

V. MODEL OF STRESS ELEMENTS

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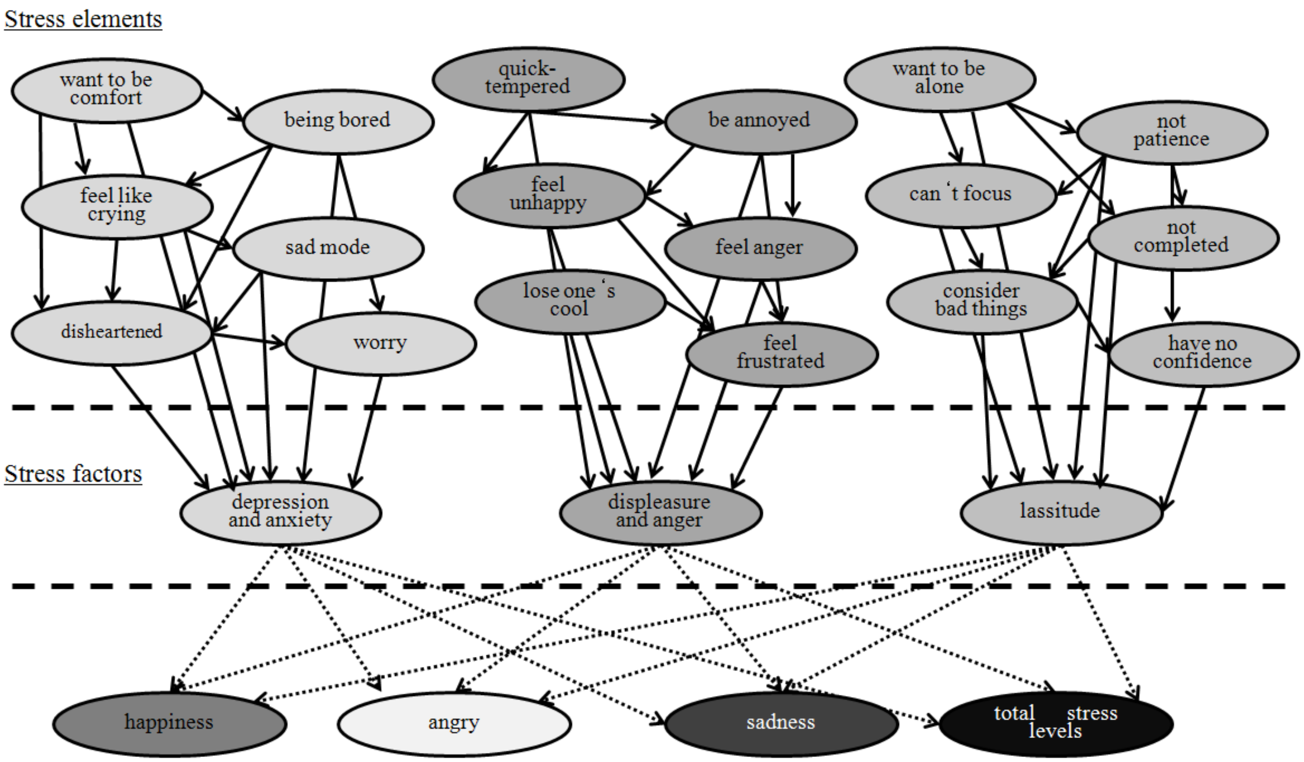

Figure 3. Stress elements model of male

A Bayesian network is a state-of-the-art knowledge representation scheme dealing with probabilistic knowledge [15]. Its nodes and arcs connect together forming a directed acyclic graph. Each node can be viewed as a domain variable that can take a set of discrete values or continuous value. An arc represents a probabilistic dependency between the parent node and the child node. We illustrate the graphical-modeling approach using a real-world case study, such as modeling and inferring human psychological stress by integrating information from intentional facial expressions and four grades, three stress factors, 18 stress attributions of SRS-18. A probabilistic psychological stress model based on the BNs is the best option to deal with the relationship between facial expressions and human psychological stress. We created a model of stress elements using BNs based on stress factors, stress elements, and facial expression intensities.

A. Definition of Variable Nodes

The stress model used in our experiment comprises 25 nodes. A stress element model was constructed from 18 stress elements, 3 stress factors, 3 facial expression intensities, and one total stress level. "depression and anxiety", "displeasure and anger", and "lassitude" of stress factor accommodate parent nodes for the six stress elements. The stress factors are parent nodes to the total stress level nodes, which are the child nodes. We set relations manually between the parent and child of facial expression intensities and stress factors. We set stress factors and expression intensity respectively as parent and child nodes based on preconditions for psychological stress influence to facial expressions. Furthermore, we set directed links for stress elements six nodes to each stress factor based on a precondition that stress elements trigger stress factors.

The 18 nodes of stress elements are assigned 0-3 points with four items: "Strongly No", "Yes a little", "Yes", and "Definitely Yes". All stress factor nodes have four grades: Level 1(i.e., weak), Level 2(i.e., normal), Level 3(i.e., slightly high), and Level 4(i.e., high).

VI. Analysis of Stress Element Model

For the analysis described in this section, we built two models given constraints on different nodes of stress factors to obtain a single simple model for which effects of stress are noticeable. Using the selected model, we attempt to analyze the type of facial expressions that are easily influenced by stress. Then, we shall analyze the stress factors and stress elements supporting them. To study differences in stress susceptibility by gender, we compare the results of analysis of stress elements in men and women.

A. Model Construction

As a preliminary experiment, we constructed models of stress elements under two constraints: "with constraints, where each factor is independent"; and "without constraints, allowing relations among elements". As it might be inferred from the contents of the preliminary experiment, no need exists to define an exact correlation between stress elements

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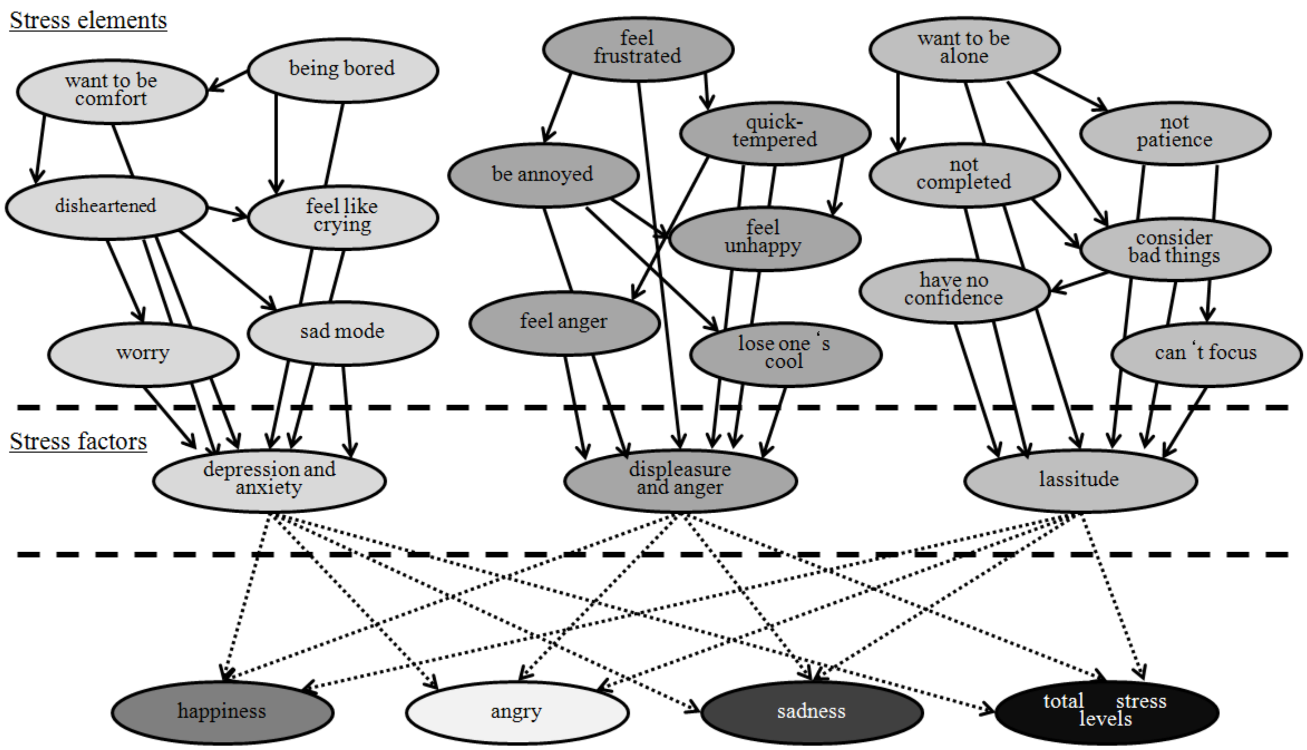

Figure 4. Stress elements model of female

because a tendency is apparent by which the probability distributions of the stress levels and expressive intensities are similar, irrespective of the presence or absence of constraints. However, the probability distribution of the model without constraints is an important characteristic for the analysis of stress elements. It is regarded as more effective when performing probabilistic inference.

Therefore, for the following experiments, we use the stress element model without constraints, allowing their relation among elements.

B. *Analytical Procedures*

The stress element models of men and women are presented in figure 3 and figure 4. Each node in stress factors, such as "depression and anxiety", "displeasure and anger", and "lassitude", has directed links of six items of stress elements as parent nodes. The directed links signify that nodes connected with them are optimized for better inferential accuracy. Therefore, a strong mutual relation exists between nodes that are connected by directed links.

The analytical procedures of stress factors that affect the facial expressions are described in the following based on the stress element models. As the flow of the entire analysis, by giving evidence to the degree of stress response, and by comparing the probability distribution of the expressive intensities "happiness", "anger" and "sadness", we strive to identify facial expressions that are sensitive to stress.

Additionally, we verify any stress elements in terms of whether they affect the expressive intensities of the facial expression.

First, we calculate the expressive intensities of three facial expressions by giving evidence to the stress response degree as "weak". Conducting stochastic reasoning based on the probability distribution of each expressive intensity, the most sensitive stress is likely to appear in any facial expression was determined. Next, we assessed the degree of stress responses of "slightly strong" and "normal" using the same procedures. We specifically examine the probability distribution of expressive intensities in three facial expressions. Furthermore, even for stress elements corresponding to each stress factor, using the same procedures as stochastic reasoning, we identify the stress factors and elements that affect expressive intensities in facial expressions.

C. *Male Model*

Figure 5 presents a probability distribution of the expressive intensities corresponding to each stress response degree in the male model. Giving evidence to the stress response degree as "weak", the probability value was also larger because the expressive intensity increases. For the case in which the stress response degree is "normal" compared to "weak", the probability value is greater when the expressive intensity is small. Moreover, in the case of "slightly strong", probability values tend to be large in all

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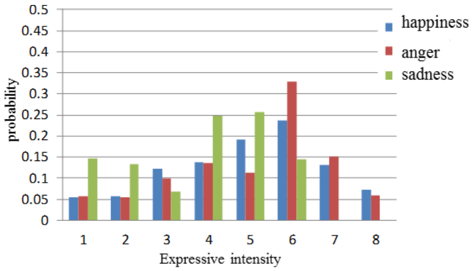
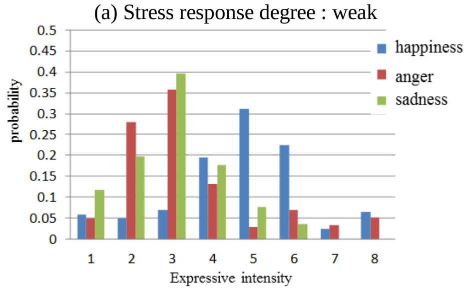
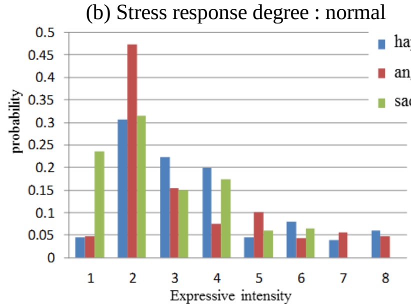


(a) Stress response degree : weak

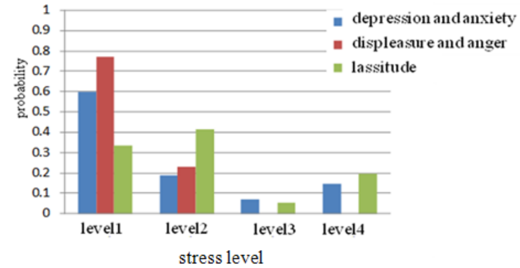


(b) Stress response degree : normal

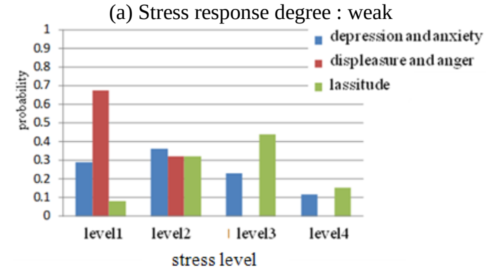


(c) Stress response degree : slightly strong

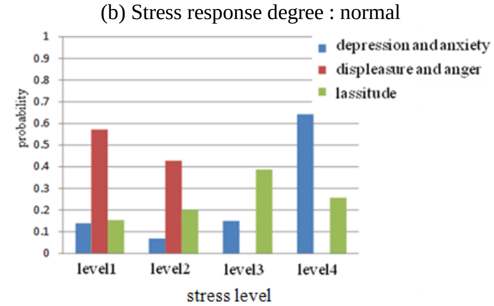
Figure 5. Probability distribution of the expressive intensities corresponding to each stress response degree in male model



(a) Stress response degree : weak



(b) Stress response degree : normal



(c) Stress response degree : slightly strong

Figure 6. Probability distribution of the stress levels with emphasis on the facial expression of "happiness "

three facial expressions, when expressive intensities are small. The results are shown as described above: when the confirmed. Estimating the expressive intensity corresponding to stress response degree is particularly difficult for facial expressions of "anger" and "sadness" because it is small in the state of "normal" stress.

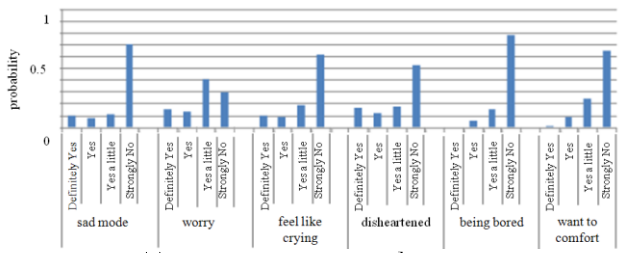
Therefore, we will strive to conduct analyses particularly addressing the "happiness" facial expression, for which the probability value of expressive intensity is changing related to the stress response degree. To analyze the stress factors and stress elements that support them on the "happiness" facial expression, by giving evidence sequentially from "Level 1" to "Level 4" for total stress levels, we identify the stress factors affecting facial expressions from their probability distributions of expressive intensities. Furthermore, we examine the link structure of the stress elements related to the stress factor that has been identified.

Figure 6 depicts a probability distribution of the stress level in each stress factor. As the stress response degree becomes higher, the level of the stress factor "depression and anxiety" indicates a high value. This phenomenon appears most significantly on the estimated value of the probability distribution. However, for the stress factors of "lassitude" and "depression and anxiety", characteristic changes are not observed in the estimated value of the probability distributions at respective stress levels.

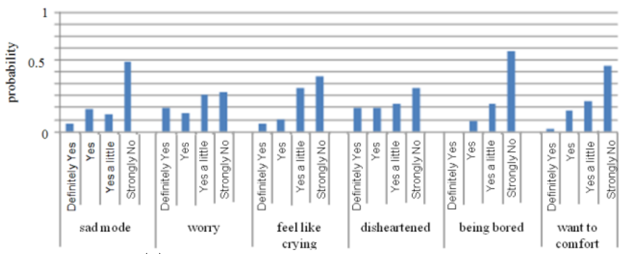
Therefore, in the male model, we consider that the factor of "depression and anxiety" affects the facial expressions of "happiness" as a stress factor. Then, as targeting the six stress elements characterizing the factors of "depression and anxiety", we attempt to identify the stress factors for supporting the relevant factor. We set evidence for the stress response degrees of "normal", "weak", and "slightly strong". Figure 7 shows the probability distribution of stress elements for each stress level. For "normal" and "weak" as stress response degrees, the highest probability value of "strongly no" denying the stress elements was identified, other probability values were less than 0.3. For "slightly strong" as a stress response degree, stress elements of "sad mood", "crying", and "disheartened" showed high probability values together for support of the cause of "definitely yes".

D. Female Model

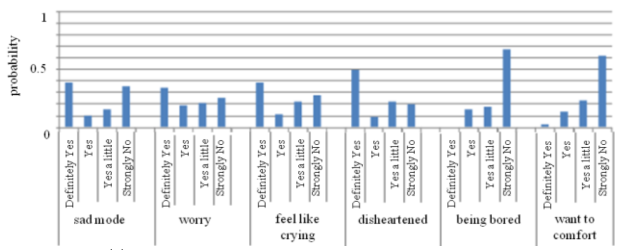
Using the same procedure as that used for the men, we analyzed the relations between stress factors, stress elements, and expressive intensities of three facial expressions for women. In the female model, a marked change was



(a) Stress response degree]e : weak

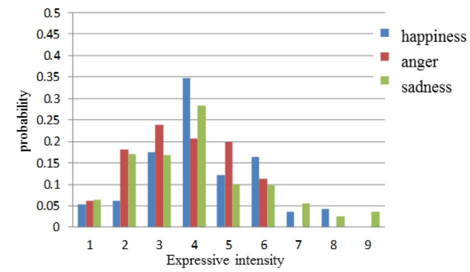


(b) Stress response degree : normal

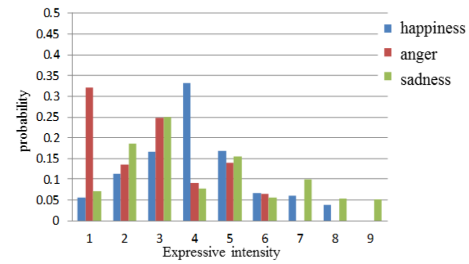


(c) Stress response degree : slightly strong

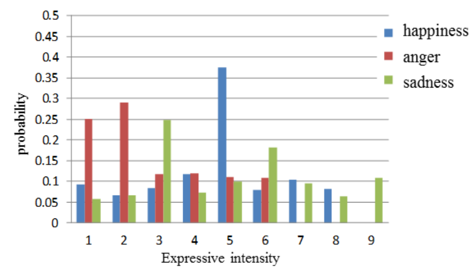
Figure 7. Probability distributions of the stress elements characterizing the factors of "depression and anxiety" in male model



(a) Stress response degree : weak



(b) Stress response degree : normal



(c) Stress response degree : slightly strong

Figure 8. Probability distribution of expressive intensities corresponding to each stress response degree in female model

recognized in the probability distribution of expressive intensity of "sadness", as presented in figure 8.

Figure 9 presents a probability distribution of stress levels with emphasis on the facial expression of "sadness" in each stress factor. As it might be understood from the contents of figure 9, particularly addressing the probability distribute-on of the factors of "lassitude" and "depression and anxiety", a considerable change is apparent with the difference of stress response degree, i.e., "weak", "normal", and "slightly strong". The probability distributions of the stress elements characterizing the factor of "depression and anxiety" are presented in figure 10. As a stress element giving influence to the factor of "depression and anxiety", the influence of "disheartened" exists to a slight degree. However, no distinctive element to support the factor of "lassitude" is found anywhere because the probability distribution shows a similar tendency to that of the change of the degree of stress response.

Based on the experimentally obtained results presented above, we conduct an examination from the perspective of stress factors and stress elements giving influence to them, specifically examining the relation between psychological stress and three facial expressions for men and women. Some facial expressions appear easily, but others are difficult to assess in psychological stress. In the male model, facial expressions of "happiness" show marked changes attributable to differences in the stress-response degree, but characteristics of the probability distribution of expressive intensities are similar in facial expressions of "sadness" and "anger". Expressive intensities become slight with the increase of stress response degree as an overall trend. In the female model, a change was observed in the characteristics of the probability distribution of expressive intensities, only the facial expression of "sadness", by setting evidence to the stress response degree as "slightly strong".

Therefore, we inferred that the influence of psychological stress appears easily, respectively, in the expression of "happiness" for men, and in the expression of "sadness" for women. In addition, the factor of "depression and anxiety" as a stress factor influences the facial expressions of "happiness". Then, as stress elements which support it, three items exist for men: "sad mood", "feel like crying", and "disheartened". Although significant changes were observed in the probability distribution of the factors of "lassitude" and "depression and anxiety", the female model did not

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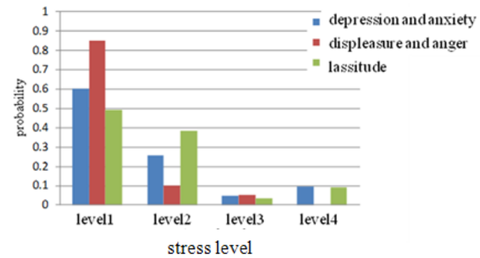
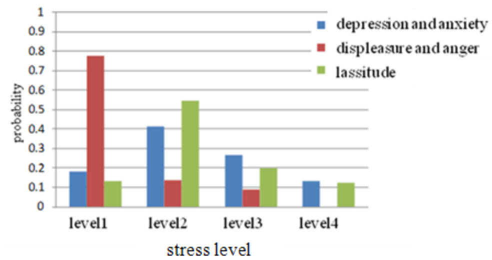
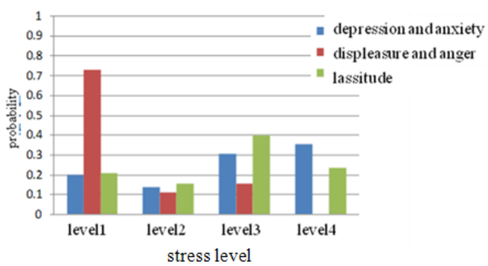


(a) Stress response degree : weak

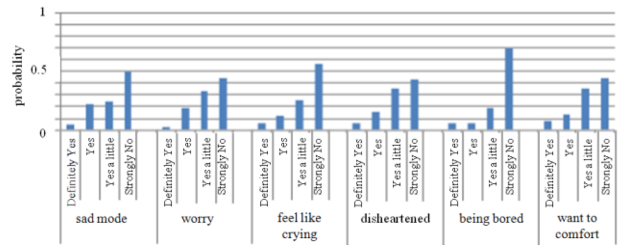


(b) Stress response degree : normal

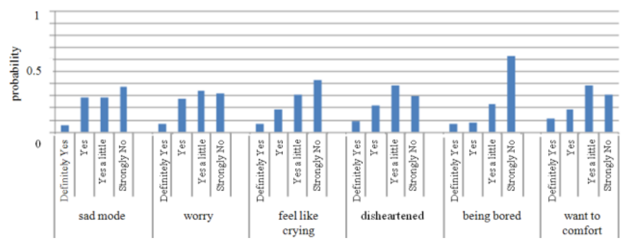


(c) Stress response degree : slightly strong

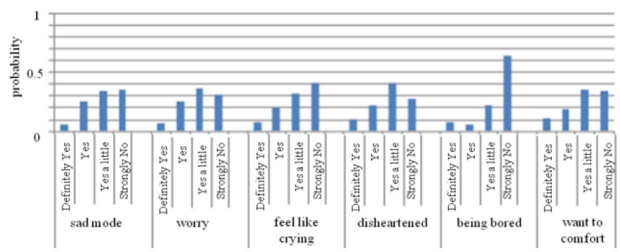
Figure 9. Probability distribution of stress levels with emphasis on the facial expression of "sadness"



(a) Stress response degree : weak



(b) Stress response degree : normal



(c) Stress response degree : slightly strong

Figure 10. Probability distributions of the stress elements characterizing the factors of "depression and anxiety" in female model

engender specific stress elements to support those stress factors.

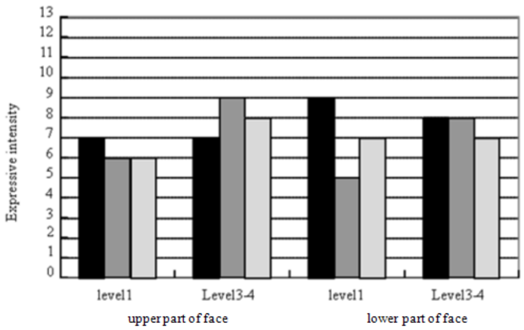
VII. STRESS FACTORS AND EFFECT OF FACE REGION

In this section, we first classify the state (slightly high) of levels 3–4 and the state (weak) of level 1 for which each stress factor holds the state of "Level 4" from "Level 1". Next, by probabilistic reasoning of giving evidence in these two states, we strive to identify the face region (upper face, lower face) in which psychological stress effects readily appear. For this experiment, we use the model of stress elements for the entire subject, i.e., the 10 university student subjects comprise 5 men and 5 women.

A. Factor of 'depression and anxiety'

Figure 11 shows expressive intensities of parts of the face, where we set evidence to the state (slightly high) of levels 3–4 and the state (weak) of level 1, assessing the factor of "anxiety-depression". Estimation results of stress levels and expressive intensities are presented in figure 11(a). The relation between types of facial expression and the differences of expressive intensity are presented in figure 11(b). These two figures are summaries for the respective face regions. The vertical axes in the figures respectively show the expressive intensity and the difference of expressive intensity. It is noteworthy that the difference of expressive intensity shows the absolute value of the difference between the expressive intensities levels "3-4" and "level 1" in respective states.

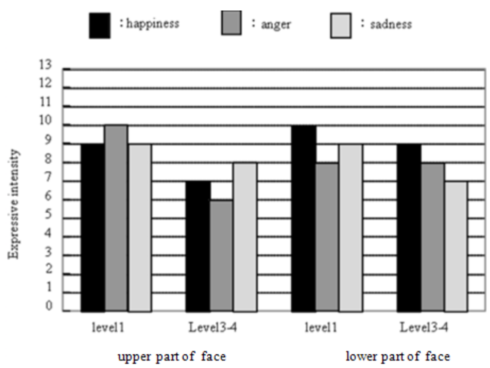
Specifically, assessing the differences of expressive intensity in "happiness", "anger", and "sadness", the respective values of the upper face are 0, 3, and 2. In contrast, the respective values of the lower face are 1, 3, and 0. In the case in which the stress factor of "anxiety-depression" acts significantly, large values have been identified for the upper and the lower face at expressing "anger". Therefore, the influence of "anxiety-depression" readily appears at expressing 'anger'. In addition, we infer that the influence affects the entire face region. These analytical results are consistent with the contents of the previous study described in 18), i.e., the emotional states of mind stimulated "anger" and "depression" are similar.



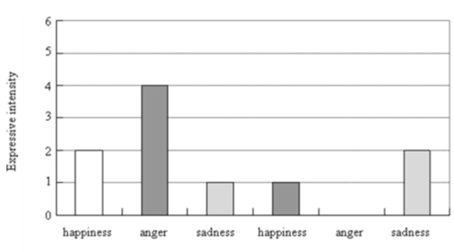
(a) Estimation of stress levels

(b) Difference of expressive intensity each face part

Figure 11. Expressive intensities of parts of the face



(a) Estimation of stress levels



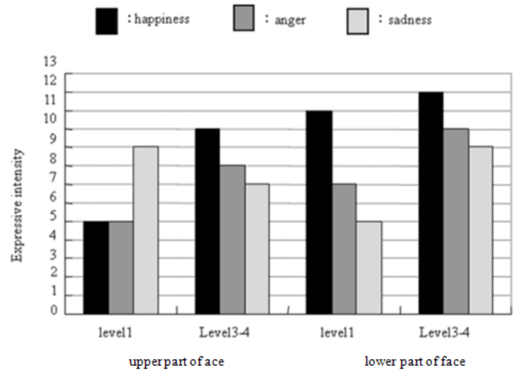
(b) Difference of expressive intensity each face part

Figure 12. Expressive intensities of each face region based on the stress factors of "displeasure and anger"

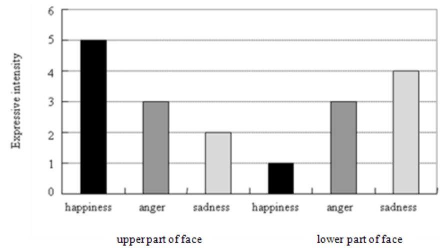
B. *Factor of 'displeasure and anger'*

Figure 12 represents the expressive intensities of each face region based on the stress factors of "displeasure and anger", as presented in the preceding section. Specifically examining the differences in expressive intensity in "happiness", "anger", and "sadness", the respective values of the upper face were 2, 1, and 4. In contrast, the respective values of the lower face are 0, 1, and 2. Accordingly, we consider that the following analysis is reasonable, i.e., the influence of "displeasure and anger" readily appears at the upper face of expressing "anger".

In addition, because we are conducting the operation of "glared" to intimidate an opponent expressing "anger", this analytical result matches a case study in which changes occur during that process, such as "eyebrows down" or "upper eyelid is raised". Consequently, the effect readily appears strongly in the upper face of the facial expression "anger", in the case in which the stress factor of "displeasure and anger" is readily apparent.



(a) Estimation of stress levels



(b) Difference of expressive intensity each face part

Figure 13. Expressive intensities of respective face regions based on the stress factor of "lassitude"

C. *Factor of 'lassitude'*

Figure 13 exhibits expressive intensities of respective face regions based on the stress factor of "lassitude". Specifically examining the differences of expressive intensity in "happiness", "anger", and "sadness", the respective values of the upper face are 5, 3, and 2. In contrast, the respective values of the lower face are 1, 3, and 4. Accordingly, we regard the following analysis as reasonable: the influence of "lassitude" readily appears at the upper face expressing "happiness", and the lower face expressing "sadness".

In general, changes in facial expressions are poor during the state of "lassitude". Therefore, a tendency to fall "expressionless" might be confirmed. However, results indicate that the influence appears strongly on the lower face for the expression of "sadness" and the upper face of the expression 'happiness' in this analysis. For this study, we adopted an experimental protocol in which all subjects intentionally express three facial expressions of "happiness", "sadness", and "anger", even when they are in the state of "lassitude". Therefore, these reasoning results reflect the characteristics of datasets based on the experimental protocol. Although the factor of "lassitude" contributes significantly, we have found out that the effect readily appears at the lower face of the expression "sadness" and the upper face of the expression 'happiness' on intentional facial expressions.

VIII. CONCLUSION AND FUTURE WORK

This study, which analyzed stress factors and elements of psychological stress on intentional facial expressions using BNs, was conducted to identify the types of facial expressions and facial parts which readily manifest the influence of psychological stress. In our evaluation experiment, we conducted stochastic reasoning to build stress elements models for all subjects, men and women, providing evidence to the stress response degree and stress factors.

Results revealed the following points.

1) The factor of "anxiety-depression" affects the facial expression of "happiness" in men.
2) The factors of "anxiety-depression" and "lassitude" affect the facial expressions of "sadness" in women.
3) The influences of "depression and anxiety" readily appear when expressing "anger", and affect the entire face.
4) The influence of "displeasure and anger" readily appears at the upper face when expressing "anger".
5) The influence of "lassitude" readily appears strongly in the lower face of the expression of "sadness", with the upper face of the expression of "happiness".

We will estimate models of stress elements longitudinal and transversal data to increase the number of subjects and the photography period. Furthermore, we will improve our method to address both intentional facial expressions and natural expressions that will be exposed unconsciously.

ACKNOWLEDGMENT

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Respiration-Posture Feedback System for Breathing Control

A challenge to develop an ambient health care system

Shusaku Nomura and Akira Kusumi
Department of Engineering
Nagaoka University of Technology
Nagaoka, Japan
e-mail: nomura@kjs.nagaokaut.ac.jp, s093355@stn.nagaokaut.ac.jp

***Abstract*—We developed a respiration-posture feedback system to control breathing involuntarily. In this system, a rubber air chamber placed under a subject's back inflates or deflates to adjust a subject's chest position slightly. By adequately regulating the movement of this air chamber in synchrony with actual respiration, respiration was successfully lengthened and deepened, just like voluntary deep breathing. Moreover, the analysis of the heart rate signal indicated that the parasympathetic nervous system, which is a prominent nervous system in the body, was also activated. This respiration-posture feedback system can be used for an at-home adaptive health care interface as part of an ambient system.**

Keywords-ambient feedback; heart rate variability; respiration; vagal nervous system

I. Introduction

Across generations and continents, breathing control has been introduced as one of the easiest and most effective approaches toward controlling the mental and somatic states. The unique breathing styles are developed when doing activities such as yoga, martial arts, marathon running, and even religious meditation. There is increasing scientific evidence in the field of biofeedback showing that breathing control affects behaviour, mental state, physiology, etc., such as the performance of tasks [1], quality of sleep, anxiety [2-5], heat rate [6-8], blood pressure [5, 9] and even immune functioning [10-12].

Moreover, the numerous medical observational and clinical studies have revealed that adequate breathing control of patients who experience a breathing-related disorder, such as obstacle sleep apnoea (OSA) or central sleep apnoea (CSA), which are prominent risk factors of cardiovascular disease [13], can significantly reduce this risk [14, 15]. Thus, developing a breathing control method is quite beneficial for maintaining health clinically and in daily life.

The wide-ranging physiological effects of breathing control are mediated by vagus nerve (parasympathetic nervous system) activation [16]. The vagus nerve, the most important nervous system in the body, is a single transduction pathway of the nerve signals that convey physiological information to the brain stem. Respiration is regulated via the parasympathetic nervous system as follows: (1) respiration induces changes in the pressure in the lung and pH in the blood, (2) these physiological changes are detected by mechanoreceptors and chemoreceptors, respectively, and then (3) the signal from each receptor is conveyed to the respiratory centre at the brain stem via the (afferent) parasympathetic nervous system (Fig. 1). Because nerves innervating the body and brain interconnect at the brain stem, respiration may be able to regulate the entire body and even mind. In other words, voluntary control of respiration could affect the entire body and the mind.

The challenge of this study is to develop a system to involuntarily (or unconsciously) control respiration. The voluntary control of respiration, e.g., biofeedback training, sometimes requires substantial effort and concentration.

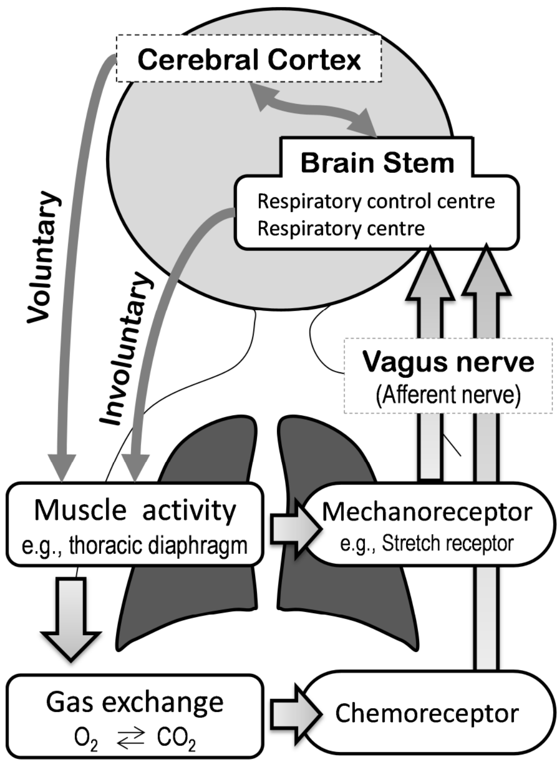

Figure 1. Respiration physiology.

Moreover, the mechanical respiration control systems that physically provide airflow to patients in the clinic, such as Continuous Positive Airway Pressure (CPAP) and Adaptive Servo-Ventilation (ASV), require patients to be fitted with a nasal cannula or respirator. Although CPAP and ASV can be the most effective treatments for patients with OSA and CSA [14, 15], they are not suitable for daily, at-home use.

We, thus, propose a respiration-posture feedback system as a novel and easy-to-use home health care system. With this system, we hypothesized that regulation of the user's posture stimulates mechanoreceptors, which then induces vagus nerve activation, unconsciously.

In the following sections, we describe the schema of our respiration-posture feedback system, present the experiment to verify the feasibility of this system and its results, and conclude by discussing the results and limitations of the study.

II. METHOD

A. *Respiration-posture Feedback System*

We developed a respiration-posture feedback system to control subject's respiration. This system comprises a respiration sensor unit, a posture regulation unit, and an interface, as shown in Fig. 2. The respiration sensor unit uses a force-sensing device (FSR400, Interlink Electronics, Inc., USA, [17]) and an electric signal amplifier to convert the movement of the subject's chest that accompanies respiration into an electric signal. The interface (NI USB-6008 DAQ, National Instruments Co., USA, [18]) converts the analogue signal derived by the respiration sensor unit into a digital signal (12-bit resolution, 1000-Hz sampling rate). Using our algorithm (described later), the digital respiration information can be used for the posture regulation unit. Posture is regulated by a rubber air chamber (Fig. 3a) placed under the subject's back and is inflated and deflated by a pair of air pumps (Fig. 3b) (YP-20A, Yasunaga Air Pump Inc., Japan, [19]).

B. *Regulation of Respiration-posture Feedback System*

The challenge of this feedback system is to lengthen and deepen a subject's breathing. To achieve this goal, we introduced posture regulation because physical movement accompanies respiration, and posture, to some extent, affects respiration. We then designed an algorithm in which the inflation and deflation of the air chamber is appropriately regulated as follows: (1) the air chamber is inflated when the subject's respiration is about to reach its peak of inspiration to extend slightly the inspiration time, and on the other hand,

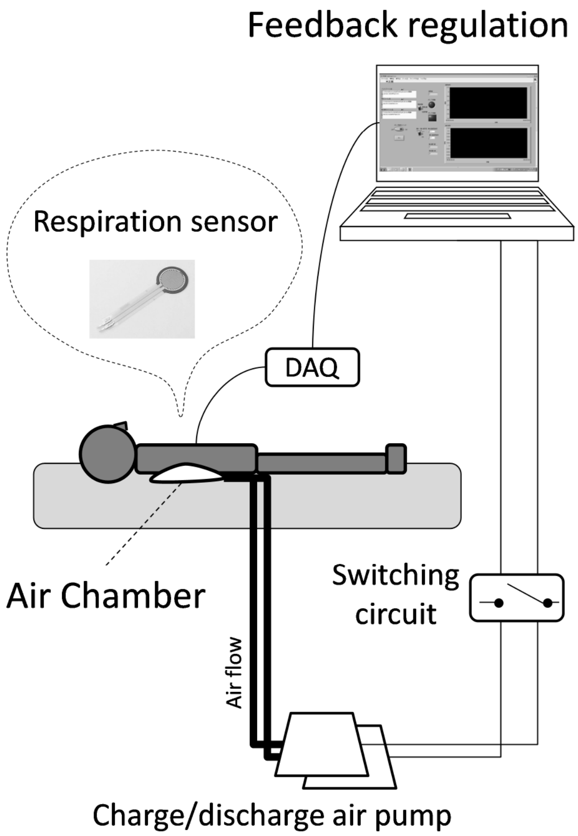

Figure 2. Schematic diagram of our respiration-posture feedback system.

(a)

(b)

Figure 3. (a) Rubber air chamber placed beneath the subject's back, and (b) air pump to inflate and deflate the rubber air chamber.

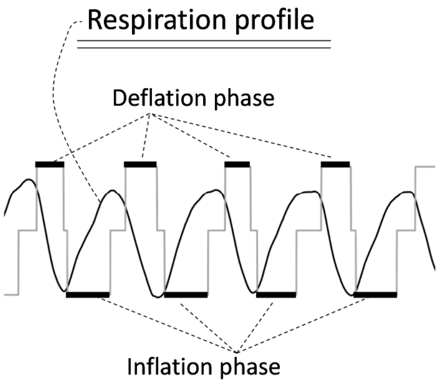

Figure 4. Profile of respiration and the feedback regulated inflation/deflation phases of the air pump.

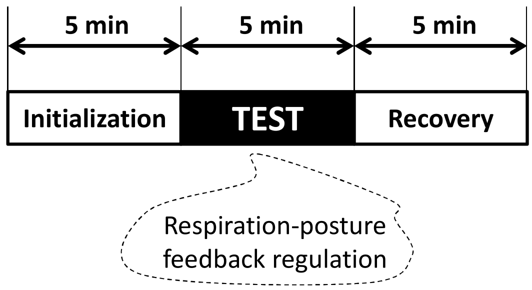

Figure 5. Experiment schedule.

and (2) the chamber is deflated gradually to slow the subject's expiration. It is not necessary for human respiration to be a regular cycle, so this regulation is implemented as a real-time feedback system. The system continuously monitors the subject's respiration via the respiration sensor unit. The signal is differentiated to determine the change in breathing speed during inspiration and overall respiration. By comparing this breathing speed signal with the subject's normal breathing speed profile that is recorded in advance, the system predicts the timing of peak inspiration and respiration during the relevant respiration cycle. The air chamber is inflated or deflated to shift this predicted respiration peak later.

Typical respiration and air pump regulation profiles are shown in Fig. 4. It should be noted that the airflow to the rubber chamber via the pump has a certain time delay, so the On/Off signal of the pump does not imply the time of inflation and deflation. Moreover, the inflation of the rubber chamber is limited to avoid placing too much pressure on the subject's back.

The regulation algorithm described here was developed using a visual programming language (LabVIEW, National Instruments Co., USA, [18]). We then conducted an experiment to confirm the effectiveness of the feedback system.

C. *Experiment*

Four male undergraduate students (age, 20–22 years) voluntarily participated in the experiment. After electrodes for obtaining the electrocardiogram (ECG, the heart beat signal) and the respiratory sensor unit were attached, the subjects were instructed to lie on a bed with the posture regulation unit (the rubber air chamber) placed under their back. As shown in Fig. 5, the experiment consists of a 5-min initialization period, followed by the regulation period, and then a 5-min recovery period (15 min in total). The respiration-posture regulation algorithm functioned only during the target period. There was no regulation at all during the initialization and recovery periods.

Subjects were instructed to stay calm and relax on the bed for the entire 15-min period, and were informed that the air chamber would be inflated and deflated during the middle of the experimental period. However, they were not told in advance how the chamber was regulated.

The experiment was conducted in the afternoon in an environmentally controlled room.

III. Results

Fig. 6a and 6b shows the results of the peak-to-peak interval and the amplitude of the respiration, respectively. It should be noted that the amplitude in Fig. 6b is shown in the form of an electric potential observed by the sensor unit of our system; it proportionally increases as the chest circumference increases. As these figures show, the peak-to-peak interval and the amplitude of the subjects' breathing lengthened and increased in magnitude, respectively, during the target period compared with initialization and recovery periods. This indicates that the subjects' respiration was slowed and deepened using our system, as we expected.

Fig. 7a shows the results of the heart rate. The heart rate declined during the period of regulated respiration compared with the initialization and recovery periods. The frequency component analysis of the heart rate variability (HRV) was also performed. Fig. 7b shows the results of the high-frequency component. The high-frequency component (range, 0.15–0.40 Hz) of the variation in the peak-to-peak interval of the heart beat in a time series, called the HRV, represents the activation of the heart-related parasympathetic nervous system [20, 21]. The vagus nerve works to slow the heart beat and increase the variation in heart beat intervals, called respiratory arrhythmia. Therefore, these heart beat profiles imply the increment of vagus nerve activity during respiration regulated by our respiration-posture feedback system.

Fig. 8 shows the ratios of the test period over the initialization and recovery periods. Although a decline in the heart rate was not observed for all subjects, a significant change in the respiration and the vagus nerve activation was observed.

With regard to subjective scoring, no subject reported any discomfort with the air chamber placed under his back.

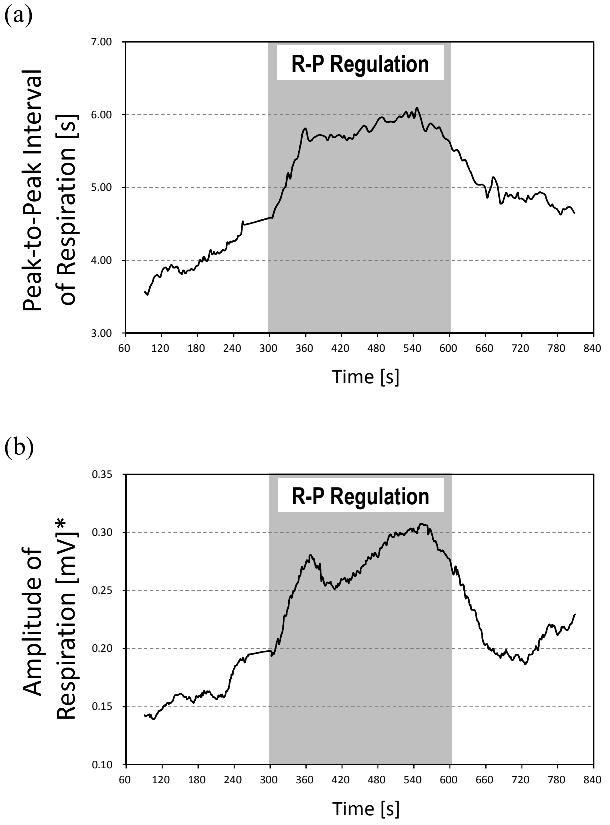

Figure 6. Profile of (a) peak-to-peak interval and (b) amplitude of respiration, respectively. The amplitude is shown in the form of electric potential measured by the sensor unit of our system.

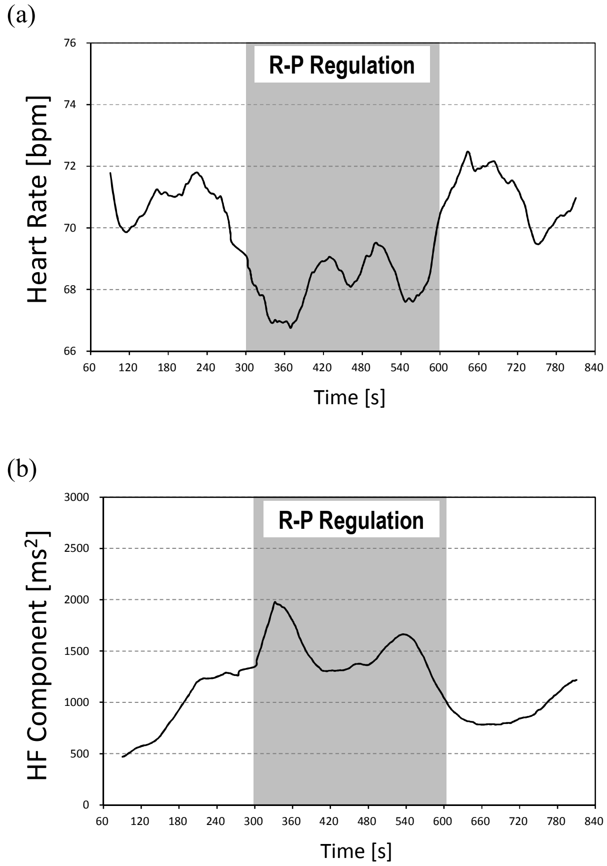

Figure 7. Profile of (a) heart rate and (b) high-frequency component of the heart rate, respectively.

The subjects were not aware of the feedback regulation of the system.

IV. Discussion

The aim of this study was to test the plausibility of our respiration-posture feedback system for controlling a subject's respiration, and, in turn, the accompanying vagus nerve activation. By regulating the inflation and deflation of the rubber air chamber in relation to inspiration and expiration peak timing, the subject's breathing was lengthened and deepened, as we expected. Moreover, the heat rate and its variability profile indicated that the parasympathetic nervous system was activated simultaneously. Therefore, it is suggested that respiration-posture feedback regulation could affect not only breathing but also human parasympathetic nervous system activity.

The parasympathetic nervous system is a prominent system of afferent nerves in the body, and conveys and aggregates the internal states of the entire body to the brain stem. Vagus Nerve Stimulation (VNS) technology, for example, employs this afferent property to stimulate the brain of a patient with symptoms of epilepsy. This is accomplished, not by stimulating the brain itself, but by stimulating the patient's vagus nerve using an electrical device implemented in the neck [22, 23]. However, it has been reported that VNS could have a side effect of the symptoms of apnoea syndrome, a pathological respiration disturbance [24]. This comes from the wide and complex network of the parasympathetic nervous system in the body, and it represents the risk of direct electrical stimulation. In contrast, our system controls the respiration, which is also closely related to parasympathetic nervous system activation, and thus stimulates the vagus nerve indirectly. Therefore, our system might stimulate the brain stem indirectly via parasympathetic nervous system activation. To verify this theory, further study is needed on a variety of physiological functions. For example, in the endocrine system, secretion of stress-related hormones [25, 26] using respiratory control is envisioned.

Implementing our respiratory control system as an ambient system for promoting daily health care at home would have an advantage compared with yoga, meditation, or conventional biofeedback training introducing breathing control. Respiration is controlled both voluntarily and

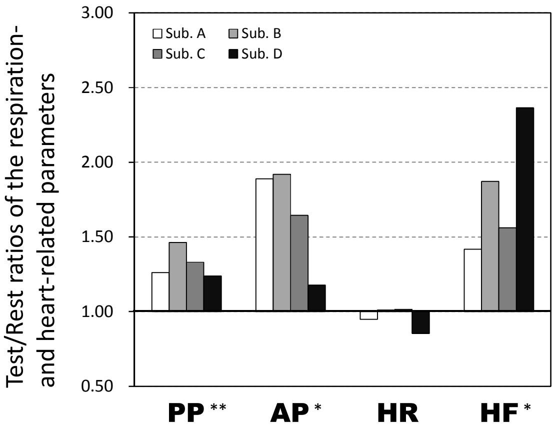

Figure 8. Ratios of the test period over the initialization+recovery period. PP, AP, HR, and HF represent peak-to-peak interval of respiration, amplitude of the respiration, heart rate, and high-frequency component of the heart rate variability, respectively. ** and * represent statistical significance by the *t*-test at $p < 0.01$ and $p < 0.05$, respectively.

involuntarily. Individuals use these relaxation activities to control their breathing by voluntary ventilation, so it requires a sufficient effort and higher concentration to maintain ideal breathing. In contrast, our system targets controlling involuntary ventilation by respiration-posture feedback regulation, which should stimulate mechanoreceptors in the body that sense the change in the air pressure and induce a variety of reflex responses needed to maintain respiration involuntarily. The user would achieve breathing control with less conscious effort, and for a longer time.

A recent population-based sleep study reported that approximately 20% of business men at a company had at least one symptom of severe or moderate OSA, and that the severity of OSA is related to metabolic syndrome [27]. A direct airflow apparatus such as CPAP or ASV is not practical for installation in a large number of patients' and/or pre-patients' homes. In contrast, because our system is a real-time feedback system that monitors the subject's respiration continuously, it could easily detect OSA and adequately inflate or deflate the air chamber to change posture and stimulate recovery from apnoea. Therefore, by developing our system, it could contribute to the field of public health and preventive medicine at both the clinic and at home.

The limitations of our study are the small number of subjects, the use of the same air chamber and its regulation algorithm for subjects with different physical attributes, and the use of a wired respiration sensor. These limitations should be improved in future studies.

V. CONCLUSION

Our respiration-posture feedback system successfully lengthened and deepened subjects' respiration, which implied vagus nerve activation.

The number of health care devices used at home is increasing, many of which can be interconnected via a wireless network [28]. Thus, the integration of biomedical engineering and information and communication technology for home health care would be an important and future direction for an ambient system, of which our system could be a part.

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Ambient Storytelling Experiences and Applications for Interactive Architecture

Jennifer Stein and Scott Fisher
School of Cinematic Arts
University of Southern California
Los Angeles, Californa
email: steinjen@usc.edu, sfisher@cinema.usc.edu

***Abstract*—This paper explores ongoing research into *ambient storytelling* experiences and applications for the built environment and presents a design prototype for Place-based, Ubiquitous, Connected, and Kinetic (PUCK) interactive architecture. Through the use of ubiquitous technologies, it is our goal to enhance environmental awareness, augment presence in the physical environment, and enable participation through ambient interfaces. This research specifically investigates ambient storytelling through responsive environments, and explores how buildings can act as animate storytelling entities that engage and interact with their inhabitants.**

Keywords- Ambient Storytelling; Environmental Media; Interactive Architecture; Lifelogging

I. INTRODUCTION

As ubiquitous computing research had predicted in the early 1990's [1], embedded computing technologies and mobile devices have become part of our environment [2], making it possible to widely connect people to the world around them. However, whereas earlier ubiquitous computing research focused on making these systems invisible and utilitarian, less has been said about the possibilities for weaving evocative and ambient interfaces for storytelling and narrative into our everyday experiences. This project specifically addressees new types of personalized, location- and context-specific interactive architectural experiences that emerge through the use of real-time environmental sensor and human data in conversation with one another over the lifetime of a building. This paper explores a design prototype entitled Place-based, Ubiquitous, Connected and Kinetic (PUCK) Experiences for Interactive Architecture.

Our current research projects and design prototypes focus on interactive architecture within the context of environmental media to enhance environmental awareness, augment presence in the physical environment, and enable participation in new ways of placemaking. Furthermore, this research investigates the idea of ambient storytelling [3], or how the built environment can act as a storytelling entity that engages and interacts with people in ambient and evocative ways. Within the PUCK application, development of personalized responsive and interactive environments arise as people spend time in and build a relationship with the spaces they inhabit habitually through a series of ongoing conversations between inhabitants and physical space.

With this in mind, PUCK reconsiders earlier notions of *genius loci,* specifically with regard to distinctions between space and place, and how the spirit of place was thought to take on a distinct character. As noted by Christian Norberg-Schulz [4], "...ancient man experienced his environment as consisting of definite character. In particular he recognized that it is of great importance to come to terms with the *genius* of the locality where his life takes place. In the past, survival depended on having a 'good' relationship to the place in a physical as well as a psychic sense." This focus on spaces having character and the importance of having a *good relationship* with places is an important underlying concept for exploring ambient storytelling and how building inhabitants can have meaningful, ongoing relationships with their buildings. Therefore, by integrating context-aware interactions with a building lifelog [5, 6] and access to backstory about an environment, ambient stories and characters emerge and present themselves through mobile and pervasive computing technologies, applications, and public displays.

This paper is organized as follows: in Section II, we discuss our overarching research approach to ambient storytelling and interactive architecture through the historical lens of lifelogging. In Section III, we describe the design prototype we designed for a newly built campus building. Section IV introduces the technical developments implemented in the PUCK prototype and the paper is concluded in Section V.

II. APPROACH

Our approach focuses on the social and participatory elements of both ambient storytelling and interactive architecture. The research project described below uses a campus building as both a character and the setting for collaborative, context-specific storytelling in which the building inhabitants become an integral part of the story world. By inviting inhabitants to engage with both the building and their fellow inhabitants, we have introduced a new paradigm for place making within a playful, personalized, and interactive environment.

Research into lifelogging and backstory further provides a groundwork for thinking about new forms of storytelling. This has guided our research into how these stories could be customized and delivered in specific contexts and locations throughout the day, which we have termed Ambient Storytelling. This term is used to describe the context-specific and location-specific stories that emerge over time and immerse inhabitants in a story world through daily interactions with a building or architectural space. This form of storytelling within the built environment is enhanced through mutual participation and collaboration between inhabitants and the building as they begin to learn from and

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interact with one another over time. The development of a personalized responsive environment therefore evolves within the context of one's surroundings, creating a deeper connection and sense of presence within a specific location.

The practice of lifelogging, or documenting and broadcasting one's daily activities with wearable computing devices, has been a recurrent topic of our research.

However, instead of people documenting their activities, we are focusing on designing lifelogs for the built environment. The notion of the lifelog has traditionally been tied to the idea of memory prosthesis for a single human participant or user. This coupling of the lifelog concept with a human participant has deep historical roots. In describing the MyLifeBits project, Jim Gemmell & Gordon Bell et al. [6, 7, 10] point consistently to Vannevar Bush's Memex system [8] as inspiration, and in particular they draw attention to the Memex as an indexing and recording system designed to augment a researcher's mental and physical experience. The centrality of a human user further embedded in Bush's description of an interconnected web of human knowledge (presaging the internet) that enables humans to share and navigate vast stores of information. But, while the imagined protagonist of Bush's tale is a human participant, our current media environment suggests a significant shift towards the recognition of non-human participants as authors and readers of sensor data in an emerging Internet of Things.

In more recent years, research focus has expanded beyond Bush's original emphasis on knowledge retrieval to subsume more experiential memory augmentation through video capture. However, this work largely retains the original assumption of an individual human participant. In the 1980s, Steve Mann began experimenting with streaming video and started recording his life using the Wearable Wireless Webcam in 1994 [11, 12]. Similarly, Bell integrated the SenseCam video recording system [12] into the MyLifeBits software. In both of these projects, the perspective of the video camera is aligned with that of a human participant observing their environment through a camera mounted to the chest or eye (a perspective that Mann has described as sousveillance [11]). However, recent research points to new perspectival orientations for lifelogging by using objects in the environment to capture video. For example, Lee et al. designed a lifelog system that captures images and other data from the perspective of objects (in proximity to humans) [10]. Nevertheless, previous research has yet to address interest in the possibility that objects and environments might themselves be positioned as the subjects of lifelogging.

Lifelogs for physical spaces therefore combines various building, environmental and human sensor data sets, as well as collaboratively-authored character development, to create an ongoing presence of a story. Through the integration of these various sensors and collaborative character development, the building itself offers a daily snapshot of both infrastructural behaviors, but also the behavior of the inhabitants of a building (movement through space, interests in context-specific information, time spent in the building). These elements, when combined, create the groundwork for ambient and persistent storytelling based on contextually relevant information collected and authored throughout the day.

For the purpose of our research, ambient storytelling takes place through the use of lifelogs, sensor networks and mobile devices within the built environment. By thinking more deeply about context and location specificity, we have experimented with what a lifelog for an architectural space might be and what backstories the objects within might contain, i.e., what a building would lifelog about, how it would communicate this lifelog to its inhabitants or to other buildings, what kinds of backstories the objects tell, and the stories that might emerge from this buildings' lifelog and backstories.

Finally, this model for ambient storytelling provides a platform for making sensor and environmental data more evocative and playful within the actual context of physical space and inhabitant activity. However, this engagement happens without explicitly revealing the data through a traditionally transparent information visualization model. Rather than simply visualizing the data that is produced and captured throughout the day, this information becomes a part of the story through ongoing conversations between a building and its inhabitants in which both learn from one another, further engaging an inhabitant in an ambient narrative experience. To demonstrate how ambient storytelling works within the built environment, we have developed a design prototype for PUCK: Place-based, Ubiquitous, Connected, and Kinetic Experiences for Interactive Architecture.

III. PUCK Design Prototype

A. Overview

PUCK explores the new conditions for interacting with architectural spaces and the kinds of evocative experiences and interfaces that emerge from these interactions. Ubiquitous and embedded technologies introduce scenarios in which objects, buildings and people produce an infinite amount of data and information, and are in constant communication with the Internet and with each other. Buildings have become dynamic, conversant entities that communicate directly with their inhabitants, objects, and other buildings through mobile devices, public displays, and ambient interfaces.

PUCK has been implemented within the School of Cinematic Arts Building (SCA) at USC as a test bed to explore the possibilities for new kinds of ambient characters, storytelling, and experiences of place to emerge within interactive environments. The SCA Building was chosen due to its new, state-of-the-art Building Information Modeling (BIM) and Building Management Systems (BMS), networks, and its unique context within the longstanding tradition of innovative storytelling at the School of Cinematic Arts. The SCA testbed contains over 4000 embedded sensors within its Building Management System, 60 WiFi access points, networked public displays, touch screens, near field communication nodes and approximately 2000 regular inhabitants populating it. For this case study, several design prototypes were implemented specifically for the SCA building. The following offers a description of how PUCK engages its inhabitants through mobile and ambient interfaces by describing how interactions progressively reveal themselves to building inhabitants through a mobile smartphone interface and various distributed environmental displays.

B. PUCK Mobile Application

The PUCK mobile application (see Figure 1) provides a platform for building inhabitants to connect to all PUCK-enabled buildings, and for buildings to connect to individual inhabitants. After downloading the PUCK application to a mobile device, the user will be detected by the specific building she enters based on location sensors, GPS coordinates, or near-field communication technologies. Once a PUCK building has sensed a user and her mobile device's presence, the building will invite the inhabitant to add that specific building location to her application for further engagement and profile development. After an inhabitant has joined a building, she will receive notifications and prompts for action from a specific building, and will begin to develop an ongoing relationship with each individual building.

PUCK experiences are context- and location-specific, therefore, inhabitants can only access information about their relationship with a specific building when they are physically located in that building. After an inhabitant adds a specific building to her PUCK app, that building will recognize her every time she enters. This recognition plays an important part in the profile and relationship development for each specific inhabitant and building, and will impact how each building engages with its inhabitants.

When an inhabitant is detected by a specific building, that inhabitant is able to access information specific to the systems, networks, and experiences for the building she is in. Different aspects of each building will slowly reveal themselves to inhabitants as they spend more time in a building, providing a record of personal experiences with a building, as well as character traits for each unique building.

Figure 1: Puck mobile phone interface

C. Environmental Interfaces

A PUCK building displays dynamic information about itself, as well as personalized information about its inhabitants based on various data points throughout the day. Visualizing the data produced by the systems embedded within buildings provides a new kind of narrative platform for telling stories about each building. This is the first point at which the character of each building is able to reveal itself, using its building system data within the context of specific physical space to communicate stories to its inhabitants. These stories emerge from fluctuations in data, often driven by changes in inhabitant behavior or system failures, and begin to make transparent the correlations between space, time and human impact throughout the day. However, the building data visualizations are not meant to be fully transparent to inhabitants, but rather draw them in to a rabbit hole of building data and systems through a somewhat mysterious public interface.

Therefore, to introduce inhabitants to all of their data-generating systems and sensors embedded within the walls, floors, and ceilings, PUCK buildings make themselves transparent through evocative data representations, revealing their inner complex systems and networks as dynamic stories of the life of the building. By drawing inhabitants into the data, PUCK buildings begin a conversation with their inhabitants about how a building responds to its inhabitants, presenting an image of how much energy and water is being consumed, fluctuations in temperature and carbon dioxide levels, wireless network activity throughout the building, and how inhabitants impact both the digital and physical landscape of buildings through their use of buildings. This point of entry into a deeper understanding of how inhabitants use buildings and how you as an inhabitant directly contribute to changes in these systems begins to reveals itself in a data visualization. Furthermore, each building uses Twitter to communicate real-time sensor data, network activity and the presence of specific inhabitants while providing context to each visualization.

Data Visualization and Twitter: Data generated by each building is presented to inhabitants in real time through a dynamic data visualization (see Figure 2). This data visualization provides a glimpse into daily building activity and is viewable on various displays within the common

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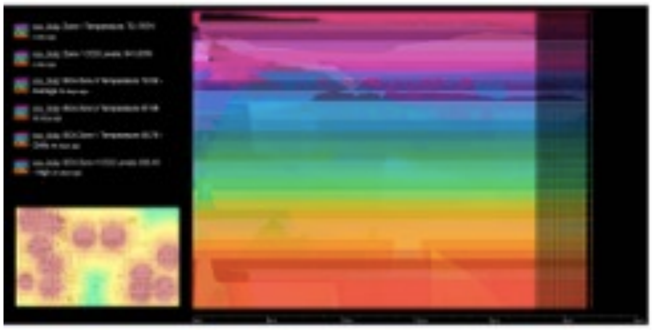

Figure 2. Public Data Visualizaion of Building Sensor Data

areas of buildings, as well as through the PUCK mobile application. This data visualization acts as the point of entry for inhabitants to engage with the building in a more meaningful way, revealing the life of the building that exists behind the walls, through its networks, and within the digital layer of the building. As inhabitants become aware of this secret life, they are invited to engage more deeply through personal interactions and conversations with the building.

To help inhabitants understand the various data points being used to generate the real-time data visualization, PUCK buildings use Twitter to tweet and display information about specific sensor readings, WiFi usage, and number of inhabitants in the building. Furthermore, inhabitants can follow each of their PUCK buildings on Twitter, contribute to a building's Twitter stream by sending messages as specific PUCK buildings, or by re-tweeting building information. Twitter also provides a social platform for buildings to reach out to their inhabitants and ask them to directly contribute information and media by engaging inhabitants in missions and other activities.

Personal Engagement with Buildings: After inhabitants are introduced to the kinds of stories the building tells through its data visualization and Twitter, the building will begin to directly engage specific inhabitants through visual and sonic interactions within the common spaces of the building (see Figures 3 and 4). By using the data a building is able to capture about an inhabitant through their mobile device, such as their presence in the building, the parts of the building they use most often, and the time of day they inhabit the building, a profile is developed by the building for each inhabitant. This is the first step towards the building becoming aware of and attentive towards its inhabitants.

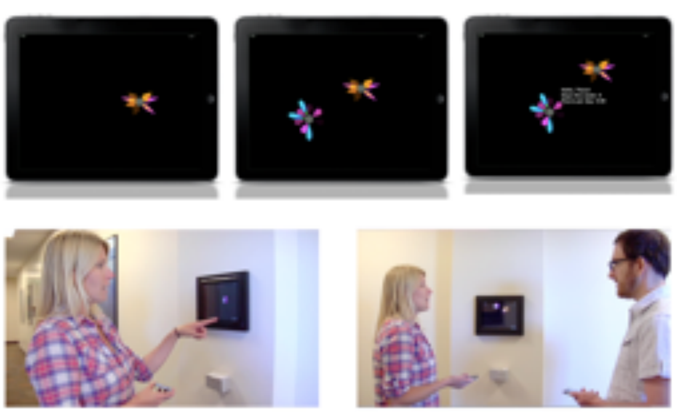

Figure 3. The building personally engages inhabitants through personalized data Identicons

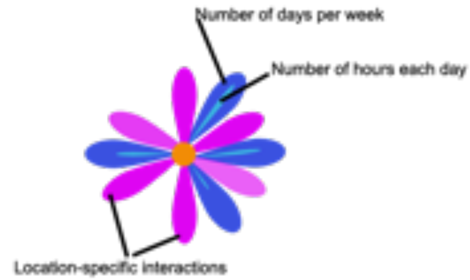

Figure 4. Personal Data Identicon

PUCK generates a graphic identifier, or identicon, for each inhabitant based on a number of variables it learns about its inhabitants. This personal data identicon is an integral part of the relationship development process and is PUCK's way of showing an inhabitant that it knows she is present, that it recognizes the personal information shared with it, and that it wishes to engage an inhabitant directly. The parameters a PUCK building uses to generate a personal identicon is based on the context of each building, but includes data such as days per week a inhabitant has spent in a specific building, hours per day, or a tally of direct interactions an inhabitant has engaged in with a building, and the locations of the building most frequented.

These identicons are revealed to each inhabitant in various ways within PUCK buildings, appearing on public screens throughout each building, as well as within the PUCK mobile application. Inhabitants receive a new identicon each week, and are able to review all past identicons on their mobile device. This provides an overview of how one's relationship with each building is progressing, and also highlights milestones reached within an inhabitant's profile and relationship development with each building. Furthermore, these identicons develop different behaviors over time, based on how one's relationship develops, current data, and network conditions within the building.

D. Data Sculpture

To communicate the significance of the process of relationship development, PUCK uses what it has collected about itself and its individual inhabitants to create a data sculpture to show its appreciation (see Figure 5). PUCK generates this data sculpture as a physical representation of digital information to show inhabitants what it has learned

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Figure 5. Personal Data Sculpture

about them, what they have learned about PUCK through their interactions, and how the two have worked together to establish a sense of place within SCA. This data sculpture is printed by PUCK into a tangible 3D object for an inhabitant after a number of milestones have been reached between the building and the inhabitant. Inhabitants are then lead to their personal data sculpture by following their identicon to a collection point within the building.

The personal data sculpture is generated using specific datasets and parameters to design an object that will always be unique to a specific inhabitant. These parameters are drawn from the data discussed above, including the overall building sensor data collected over a specified amount of time, each of the inhabitant's personal data sets, i.e., days of week spent in the building, number of hours each day, and milestones reached in their relationship development. The result is a generative model that is then printed using a 3D printer.

IV. Technical Implementation

PUCK has been designed with a combination of off-the-shelf technologies, custom hardware and software, and open-source applications. Much of the off-the-shelf technology was creatively reappropriated to meet the needs of PUCK. The result is a unique set of technologies and interactive systems that has provided a preliminary framework for ongoing research into data collection and more robust indoor location tracking through wireless access point triangulation.

A. Data Collection and Visualization

The data visualization is driven by real-time sensor data collected by the Building Management System (BMS), data tunneling OPC software, MySQL Database, Google App Engine (GAE), Python web services, and Processing.js.

To access building sensor data, the BMS data, i.e., temperature, CO_2, energy use, is tunneled from a facilities server and logged in a MySQL database on the virtual server. This allows us to format the data most usable for our purposes. Our virtual server then posts data from MySQL to the GAE data store through a web service interface. A Python web service was created to make a call to the data store to get a snapshot of the last update was from the MySQL database. This data is then reformatted into a Comma Separated Value (CSV) file, which was used to dynamically update the data visualization.

The Data Visualization is written using Processing.js visual programming language to be easily displayed on the web. This program looks for the updated CSV data from the Python web service, and updates with new data every 6 minutes as new data was generated, making the visualization dynamic through near real-time data. The CSV data is also archived so that a snapshot of 24 hours worth of data is viewable as data is generated and the visualization grows. Furthermore, the building Twitter feed was displayed along side the visualization, which would use the building sensor data being generated to send Twitter messages with sensor locations and current readings.

B. Indoor Location Tracking and User Engagement

A number of options for passively tracking inhabitants were explored during the development of PUCK. Global Positioning System (GPS) technology was initially tested but was ruled out early due to lack of signal within the building, and also could not provide the level of data granularity for each inhabitant. Radio Frequency Identification (RFID) and other near field communication (NFC) technologies were explored but did not provide the passive collection of data.

In order to passively collect data that would be linked to each specific inhabitant, we looked for a technology that could be directly connected to a mobile phone so that data could be transmitted to a server and be linked to an inhabitant's device identification. We, therefore, explored the ANT+ protocol [13] for wireless sensor networks. The ANT+ protocol is most widely used in Heart Rate Monitors (HRM) and speed sensors for fitness monitoring and tracking. This protocol allowed us to use and modify off-the-shelf sensors and devices to accomplish the desired level of data collection related to a specific inhabitant, but also limited our options to using only the mobile phone for personal data collection in this iteration.

To determine an inhabitant's location using the ANT + wireless sensor network protocol, we designed location nodes that were distributed throughout the building. These nodes consisted of heart rate monitors connected to Arduino Mini microcontrollers and potentiometers, and were a creative hack that was necessitated by a technical hurdle. We discovered through the design process that heart rate monitors only transmit a signal after they have detected a user's heartbeat. Because we were not using the heart rate monitors for their intended purpose, which is to detect and monitor a human heartbeat, the heart rate monitors needed to be modified. We require the HRM's to constantly send

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out a radio signal that could be detected by the ANT+ sensor plugged into the mobile phone. To do this, the HRM's are connected to the Arduino Mini and a potentiometer to regulate the signal at a constant output. Each location node is assigned an ID number that corresponded to a location in the building. When the mobile phone sensor detects a signal from a location node, that location ID information is pushed to Google App Engine and we can then determine where in the building an inhabitant currently is.

The mobile application was developed to detect the specific building in which it is launched. The current application detects a specific radius around the GPS coordinates for the campus building. When the app is launched within those coordinates, it displays an inhabitant's personal statistics of use for that building. At the same time, the code that has been written to scan for the nearest three HRM radio frequencies runs in the background of the current interface application. As the phone scans and recognizes the nearest HRM's through the mobile phone ANT+ sensor, this information is updated in real time to Google App Engine throughout the day and will also procedurally generate the development of an inhabitant's Identicon within the application. Furthermore, because the scanning application looks for the nearest three HRM's, it can also determine which direction the inhabitant is moving in through triangulation.

A tablet application is also used to display real-time information and personal Identicons as each inhabitant navigates the building. The tablet app has been developed using the Unity game development tool so that we can create dynamic assets in real time to be displayed on the tablets. The location node information that is sent to Google App Engine from the mobile phone sensor informs the tablet application where an inhabitant is and displays his or her personal Identicon on the corresponding tablet, which is associated with a specific location node ID. This allows the personal Identicons to follow inhabitants as they move through the building with their mobile application launched. Furthermore, each Identicon is procedurally generated in Unity from the real time Google App Engine data so that the Identicon in constantly updated to reflect the data that the inhabitant is generating as he or she navigates the building.

V. CONCLUSION

PUCK highlights important questions about how inhabitants come to understand and engage with ambient interfaces, ubiquitous computing systems, and context-specific interactions with the built environment. PUCK uses sensors, displays, and location to engage and teach inhabitants about the data being gathered on a daily basis. This data becomes a part of an emergent character of the building, in which stories emerge through data visualizations, personalized responses delivered to each inhabitant, and through data sculptures that tell the story of each inhabitants engagement with the building. This engagement with the system over time becomes a vital part of each inhabitant's personal profile and the relationship that emerges between the building and its inhabitants.

PUCK is meant to raise questions about how we think about and engage with the spaces that we inhabit, those that exist somewhere between being purely physical and somewhat digital. Lastly, PUCK brings to light concerns of privacy and surveillance by making the active profiling and data collection transparent, while engaging you in an active conversation about the future of interacting with environments that sense, generate data, and teach their inhabitants while simultaneously learning from them.

ACKNOWLEDGMENT

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Robot Localization With DASH7 Technology

Jan Stevens, Rafael Berkvens, Willy Loockx and Maarten Weyn
Faculty of Applied Engineering - CoSys-Lab
University of Antwerp
Paardenmarkt 92, B-2000 Antwerp, Belgium
{jan.stevens}@ieee.org
{rafael.berkvens, willy.loockx, maarten.weyn}@uantwerpen.be

***Abstract*—Robot localization needs to be solved in order to use the robot for other purposes. In this paper, we examine the feasibility of DASH7 tags, operating on the 433 MHz unlicensed band, for locating mobile robots in domestic environments. We achieve the same level of accuracy as laser range finder based localization, while using less processing power. Our results indicate that DASH7 can be used for robot localization, solving the robot localization problem.**

Keywords*—*Localization, DASH7, WSN, Robot, AMCL

I. Introduction

DASH7 is a new, emerging standard for active Radio Frequency Identification (RFID) and uses a 433 Mhz frequency. On the Media Access Control layer it supports Wireless Sensor Networks (WSN), but has many advantages over traditional WSN technologies, as described by Laurijssen et al. [1]. These include lower power usage, improved range, and better battery life. Recent advances in tag development will allow us to use DASH7 in various commercial applications, such as building automation, smart energy, location-based services, mobile advertising, automotive, and logistics within the next few years.

Robot localization in mobile robotics can be divided into two key problems, as shown by Dellaert et al. [2]: global position estimation and local position tracking. The global localization problem deals with a robot that does not know its initial position and has to locate itself. The robot is placed somewhere on the map; therefore, the uncertainty of its location is uniformly distributed over the map. The local localization problem is much easier because the initial position of the robot is known, so only small compensations have to be made for the odometric drift.

Static landmarks can improve both localization problems. Hahnel et al. [3] showed that RFID technology can be used as static landmarks that improve the global and local localization problem. This paper uses key concepts of the work of Hahnel et al. [3], but uses the new upcoming DASH7 tag technology.

The remainder of this paper is organized in the following sections. Firstly, we describe the main goal of this research in the following section. Secondly, in Section III we discuss the used materials for this research. Thirdly, we describe the methods in Section IV. Fourthly, we explain the achieved results in Section V. Finally, in Section VI, we provide a conclusion for this research.

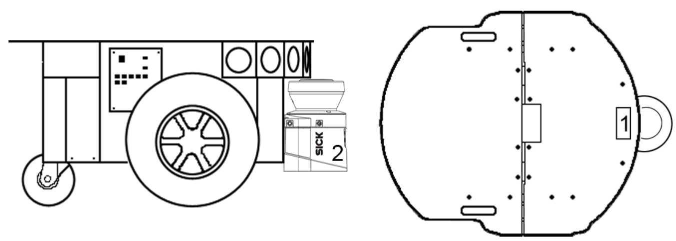

Fig. 1: Location of the different sensors.

II. Main Goal

The main goal of this paper is to examine the feasibility of DASH7 tags for locating the robot in a domestic environment. The DASH7 tags' position in the environment is known. The traditional laser range finder based localization is compared with DASH7 based localization, and DASH7 and laser range finder combined.

III. Materials

We use a mobile robot equipped with one omni-directional DASH7 antenna mounted on top of the robot. The robot is an off-the-shelf Pioneer P3-DX [4]. It is a standard robot platform that is widely used in the academic world [5]–[8]. It is equipped with a laser range finder, the Sick LMS-100 [9], which is mounted in-front of the robot. The laser range finder is a basic model with a good price/quality ratio and a 270 degrees field of view. For this research, we limit the field of view to 180 degrees. A Raspberry Pi [10] ARM processing unit is used because it is cheap and has a large developer community. The ultrasonic array, that comes by default with the Pioneer P3-DX, is not used in this research. Figure 1 shows the location of the various sensors discussed in this section. The number one indicates the DASH7 receiving tag and two indicates the laser range finder. The left image shows the side view of the robot with the laser range finder in front of the robot. The right image shows the top view of the robot with a DASH7 receiver tag on top of the robot.

Two different types of antennas are used for the DASH7 receivers and transmitters, as shown in Figure 2. The receivers have a whip antenna, because it performs better than the onboard short Printed Circuit Board (PCB) stub antenna of the transmitters. The transmitters have a holder with two AA batteries to provide power and make them portable, so they can be easily mounted against various objects.

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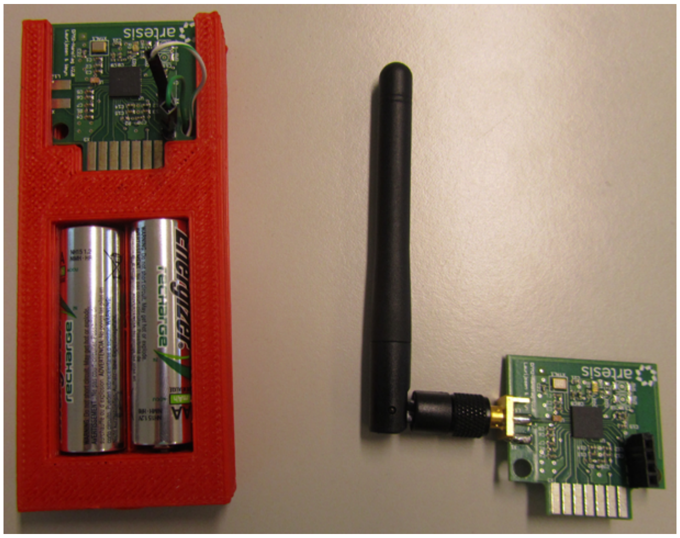

Fig. 2: Transmitter tag on the left, receiver tag on the right.

IV. Methods

A. Bayesian Filtering

We use a non-linear recursive Bayesian filter for localizing the robot, explained in Section IV-C. An advanced technique for implementing the recursive Bayesian filter is a particle filter, described by Thrun et al. [11], using the sequential Monte Carlo method [12].

Monte-Carlo Localization (MCL) is a particle filter used for localization and is a version of probabilistic Markov localization, as shown by Burgard et al. [13]. The key concept is to represent a posterior belief by a set of K weighted, random samples called particles. A set of particles represents an approximation of a probability distribution. Particles in MCL contain the robot position, heading direction and a numerical weighting factor analogous to a discrete probability. The algorithm proceeds in three phases:

Motion The motion model resembles the movement of the robot. Every particle in the current set is moved according to the motion model.

Measurement When the robot sensors are read, the measurements are incorporated in the algorithm. The particles receive a new weight by recalculating the probability of a measurement if the particle is specified.

Resampling A new particle set, of K new particles, is created from the current set, by selecting particles from the set, where each new particle is chosen with a probability proportional to the weight of the old particle. This results in particles with a low weight to have a high chance of being ignored, while particles with a high weight to have a high change of being duplicated multiple times. A normalizing factor enforces a probability distribution over all the particles.

B. Tag Detection

Detecting the DASH7 tags is done by using the Received Signal Strength (RSS). A particle filter, as described in Section IV-A, is used for locating a detected tag. Our idea is based on the works of Hahnel et al. [3], which used two directional antennas mounted on the robot to find RFID tags. We use the same idea and create a sensor model from the antenna patterns to update the particle filer and so locate our DASH7 tags. The following aspects need to be considered when creating a sensor model for the DASH7 tag.

1) There are a considerable amount of reflections when using a 433 Mhz frequency indoor.
2) Additionally, the RSS value will fluctuate even more when tags are not properly aligned.
3) Because of antenna coupling the RSS value will fluctuate within the distance of two times the wavelength.

When using the tags indoor, metal objects will generate reflections that have a lower RSS value than the transmitted power. The orientation of the tag with respect to the receivers on the robot influences the RSS value. When the tags are not aligned, different RSS values are received for the same distance. All these considerations must be taken into account before creating a sensor model.

The ratio between the RSS value and the distance from the tag must be determined so the sensor model can be applied correctly. The results in Section V-A indicate that no clear ratio can be extracted from the RSS value alone. A typical directional Yagi antenna for 433 MHz is 75 cm long and 45 cm wide, which is very impractical to mount on the Pioneer P3-DX robot.

Taking in account the practical limitations and the DASH7 considerations, we adapted our initial idea and decided to use fixed tags in the environment. The algorithm knows the exact location of the DASH7 tags and uses a simplified model to update the weights of the particles. From the results in Section V-A, two different thresholds can be determined. A tag with a received RSS value between 0 dBm and -60 dBm is assumed to be in the range of two meters, and when it has a value between -60 and -80 dBm we assume it is six meters in range. We use lower ranges than described in the results because we have to account for a cluttered environment. This results in ranges for two meters between zero and -70 dBm and for six meters between -70 dBm and -90 dBm.

C. Robot Localization

The Adaptive Monte Carlo Localization (AMCL) algorithm is used to determine the location of the robot. The AMCL algorithm, as shown by Fox [14], is based on a particle filter discussed in Section IV-A. It lowers the amount of particles needed and improves the performance on the on-board ARM computer. In the first stages of global localization, the robot is completely unaware of where it is. Therefore, a lot of particles are needed to represent this uncertainty. During position tracking, the uncertainty is rather small and can be represented with fewer particles.

The key concept of adaptive particle filters is to determine, at each iteration of the particle filter, the number of particles that are needed to represent the true posterior distribution. The main goal of a particle filter is to estimate this posterior. The solution to this problem is to rely on the particle representation in the measurement step, described in Section IV-A, and use it as an estimation of the true posterior.

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The Kullback-Leibler distance (KL-distance) is a measure of the difference between two probability distributions, as shown by Cover and Thomas [15]. The distance between the sample-based approximation and the true posterior is calculated using the KL-distance, hence the name KLD-sampling.

The KLD-Sampling algorithm calculates the amount of particles needed during the resampling step, as described in Section IV-A. The particles are placed in bins, depending on their location and angle. The bins have a specific size and angle, and can be seen as a 3D histogram, with x, y, and angle as the three dimensions. The algorithm works in the following way: First, a particle is placed in a bin which is then marked as full. Next, all occupied bins are counted and the new amount of particles needed to represent the true posterior distribution is determined. Finally, we see if we have enough particles in the new set and return. The algorithm is repeated for every particle in the current set until the new set has the right amount of particles. When the size of the bins are small then fewer bins are needed in order for the algorithm to stop, compared to a large bin size. The more bins used, the more particles are needed.

A multidimensional binary search tree or kd-tree, as shown by Bentley [16], is used to keep track of the different bins. Using a search tree, bins can be easily found and updated. The tree is also used to keep track of multiple hypothesis and calculate their variance and mean.

The simplified model for converting a RSS value to a specific distance, discussed in Section IV-B, can then be used in the AMCL algorithm. The calculated distances from the RSS value will determine how the weights of the particles are updated. A particle that is closer to the measured tag than the calulated distance is called an *inside particle*. A particle that is farther away from the measured tag than the calculated distance is called an *outside particle*. For these two thresholds the following method is applied. Firstly, if the threshold is two meters, all the inside particles' weight is multiplied by 0.9, and the outside particles' weight by 0.1. Secondly, if the threshold is six meters, the inside particles' weight is multiplied by 0.7, and the outside particles' weight by 0.3.

V. Results

A. Tag Detection

An experiment is conducted to determine the ratio between the RSS value and the distance from a tag. A transmitter is fixed at the same approximated height as the tags on the robot. The robot drives slowly away from the tag in a straight line. Every second, the transmitter sends out a packet. The RSS value of those packets are plotted in Figure 3. The described experiment is run in an indoor, open environment. The RSS value first decreases with little fluctuations. After four meters, the robot came near tables and chairs and the RSS fluctuates. When repeating the test in an environment with more objects the RSS value cannot be linked to a specific distance. From this graph, only two possible regions can be identified. The robot is very close to a tag and the robot is somewhere near a tag.

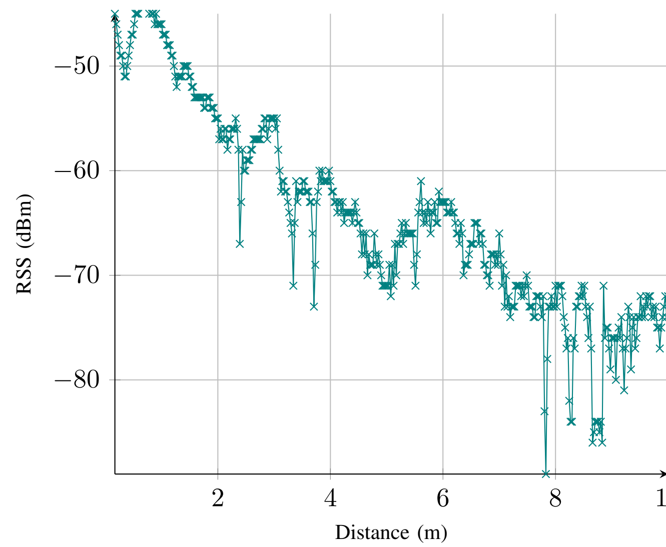

Fig. 3: The RSS value from a robot that drives away in a straight line from a tag. Experiment is run in an indoor open environment

B. Standard Deviation

Before we can use laser range finder based localization, the standard deviation for the particle filter needs to be determined. It influences how the weights are distributed for a laser range finder measurement. We started with a very small distance, making the particles stick closer together, and then slowly increase the distance. The robot drives around and at the last checkpoint, number 15 in Figure 5, we see how far the localization estimation differs from the ground truth. During the experiment we keep track of how many times the particle filter needed to reinitialize itself. This happens when the total weight of all the particles becomes zero. Figure 4 shows the result of the described experiment. The number next to a data point indicates how many times the particle filter reinitialized. The y axis shows the Euclidean distance error for x and y, and the error bars indicated the variance of the hypothesis.

On the graph, we see that after 3.5 meters, we do not need any reinitialization of the particle filter. When we look at the acquired accuracy of the localization, using the different parameters, we clearly see that the accuracy staggers after 3.5 meter, meaning that increasing the standard deviation will not result in a increase accuracy of the algorithm. We do see an increasing variance with values above 3.5 meter. The values below 3.5 meter sometimes have a very good accuracy, but also require a high amount of reinitialization. When a higher value than 3.5 meters is used, the robot has more possible hypothesis with a higher variance indicating its uncertainty of its current position estimation.

For the reasons described in the results, we use a standard deviation of 3.5 meters. It shows no reinitialization of the particle filter and provides the smallest variance with an equal error, compared with higher distances.

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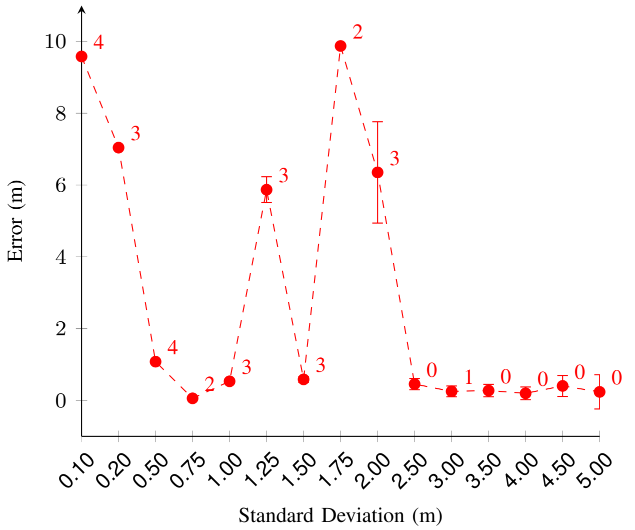

Fig. 4: Graph showing different tested standard deviation values.

C. Localization Comparison

For localizing the robot, the same office environment is used in every experiment. This environment consists of an office, hallway and conference room. Figure 5 gives an overview of two different paths and the location of the different DASH7 transmitting tags. The numbers indicate the different checkpoints, the circles are the DASH7 tags. The top floorplan shows the first path, the bottom figure shows the second path. The localization uses the AMCL algorithm described in Section IV-C. An experiment is conducted to compare the different sensors that are used in the algorithm. At every checkpoint on the different paths, the information about the particle filter is saved. The error value and variance of the best hypothesis is used to compare the different sensors in the AMCL algorithm. This experiment is repeated for every sensor: laser range finder, DASH7 tags, and DASH7 and laser combined.

Figure 6 shows the results of the experiment for every sensor, using the first robot path. We clearly see that laser range finder based localization needs more information before it can converge to the position of the robot. After checkpoint eight, we see that the laser has the same error as other sensors and has around the same variance. For DASH7 based localization, we see that it converges very fast to the right position with a large variance. After checkpoint five the variance lowers and the global localization of the robot turns into local position tracking. This comes because there is a DASH7 tag very close to the starting position of the robot, as indicated in Figure 5. The values are acquired by taking the average value of four measurements using a specific sensor. The x axis show the different checkpoints and the y axis shows the Euclidean distance error for x and y. The combination of DASH7 and laser gives mixed results. The DASH7 tags undo the negative effects of slow convergence from the laser range finder, but do not increase the accuracy of the particle filter. The error is the same for the DASH7/laser localization compared with the DASH7 only localization.

Fig. 5: Location of the different sensors on the laser generated floorplan.

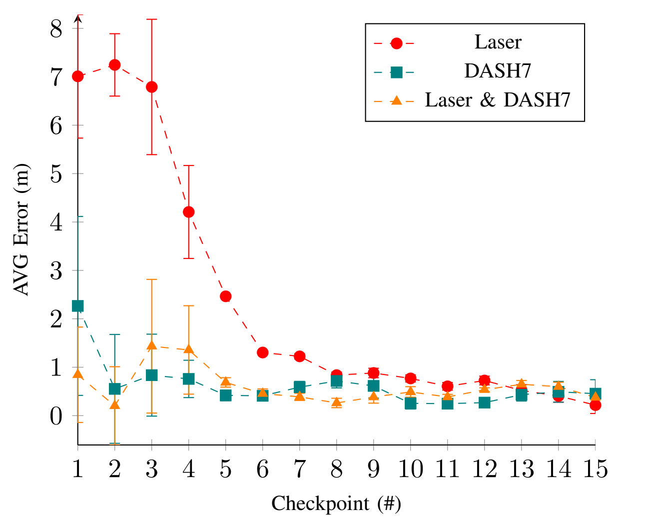

Fig. 6: The accuracy of the different sensors compared at the checkpoints using the first path.

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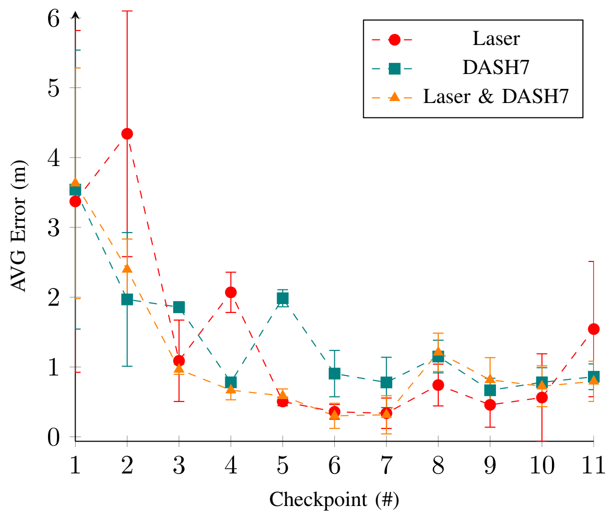

Fig. 7: The accuracy of the different sensors compared at the checkpoints using the second path.

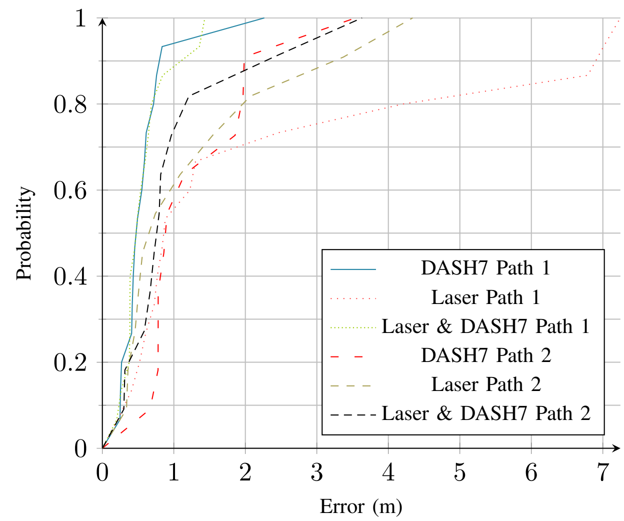

Fig. 8: CDF for the different paths and sensors.

The results of the second path in the same environment are shown in Figure 7. The values are acquired by taking the average value of four measurements using a specific sensor. The x axis show the different checkpoints and the y axis shows the Euclidean distance error for x and y. We see that the laser range finder based localization converges with the same rate as the DASH7 based localization. We explain this by examining both starting positions in Figure 5, for the first path we start next to a tag, so it converges very fast. However, the second path does not start next to a tag so the DASH7 localization needs more information before it can converge to the position of the robot. The combination with DASH7 and the laser range finder does improve the global localization.

All the different sensors can be used in the AMCL algorithm for successfully locating the robot, and, at the last 4 checkpoints, they have the same accuracy, but a difference in variance. The laser range finder has a higher variance then the DASH7 based localization.

Figure 8 shows the Cumulative Distribution Function (CDF) for every sensor in both paths. We see that for path one the DASH7 based localization and Laser and DASH7 localization, outperform the other sensors. For path two, DASH7 achieves the same performances as the laser and combining them results in a better localization.

Figure 9 shows the time it takes to acquire a sensor reading and apply this reading in the measurement model of the particle filter. For the experiment we used 1500 particles and took the average of 1000 measurements. The laser range finder and DASH7 use around the same amount of time to read in the sensor information. We clearly see that DASH7 only requires a fraction of the time to update the weights in the measurement model compared with the laser range finder. The results show that DASH7 is five times faster then traditional laser-based localization.

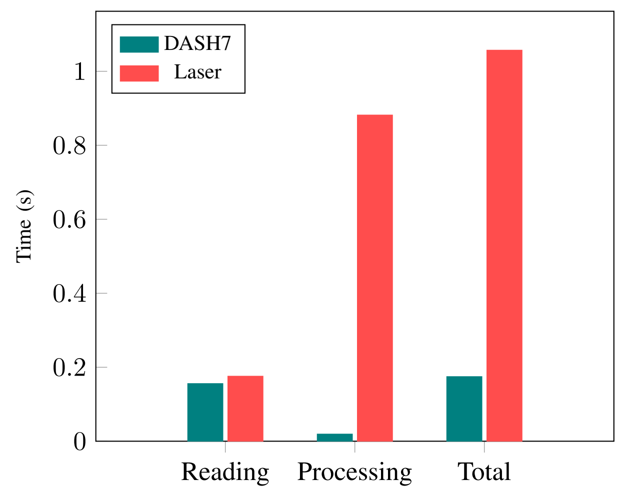

Fig. 9: Shows the time it takes for reading a measurement from the DASH7 tags and laser range finder, and applying the measurement in the particle filter.

VI. Conclusion

In this paper, we presented a new localization method based on DASH7 technology. Our approach involves the use of the AMCL algorithm to localize the robot. We use a simplified sensor model to update the particles. We have successfully implemented our approach and presented with the comparison of the different localization methods. Our results indicate that DASH7 can be used for localization and converges faster than typical laser range finder based localization. Combining laser and DASH7 slightly improves the accuracy of the localization, but results in a more computational heavy algorithm. DASH7 has more advantages than the laser range finder and preforms better in our experiments. It requires less computational power to achieve the same error and variance compared with laser range finder based localization. The amount of tags used in the environment will greatly influence the accuracy of the DASH7 based localization. More research has to be conducted

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to understand the influence of the amount of tags on the localization. To our knowledge, this is the first implementation of robot localization with DASH7 technology.

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Cross-Device Interaction

Definition, Taxonomy and Applications

Florian Scharf, Christian Wolters, Michael Herczeg
Institute for Multimedia and Interactive Systems (IMIS)
University of Luebeck
Luebeck, Germany
{scharf, wolters, herczeg}@imis.uni-luebeck.de

Jörg Cassens
Institute for Mathematics and Applied Informatics
University of Hildesheim
Hildesheim, Germany
cassens@cs.uni-hildesheim.de

***Abstract*—This contribution proposes a definition and taxonomy of the often used term cross-device interaction. Despite of technical progress, systems and interfaces that integrate into the environment are still the subject of intensive research. We still live in a world where devices reside in the foreground and present themselves and their interaction capabilities to the user. At the same time, computing devices become an integral part of our environment, be it in the form of public displays or mobile computers. Furthermore, the number of devices a user owns or has access to is increasing. Humans interacting consciously with multiple devices can be seen as an intermediate stage towards ambient environments or ubiquitous computing. The term cross-device interaction (XDI) is often used to refer to the underlying interaction paradigm in such environments. Unfortunately, the term still lacks consistent and concise definitions. This can be a problem as different authors use the term XDI with divergent meanings within a wide variety of application contexts. To mitigate this problem, we propose a taxonomy and give a user-, space- and interaction-centric definition for XDI. Additionally, we make use of this taxonomy to classify XDI-scenarios found in the literature and the concepts of XDI they exhibit.**

Keywords-human computer interaction; computer interfaces; context awareness; collaborative work; ambient computing.

I. INTRODUCTION

Although we are still far away from the all-embracing vision of ubiquitous computing, the future as discussed by Weiser [22], Norman [14] and others slowly finds its way into the world. However, computers still do not *"weave themselves into the fabric of everyday life until they are indistinguishable from it"* [22], but they are getting smaller and are potentially hidden within other technologies or environments. However, unlike described in the visions, in most cases they are still perceived as electronic, computer-driven devices that need to be configured, networked and used in some peculiar way. The actual state we are in has been described by Weiser as Phase I of ubiquitous computing. It is a phase, which is said to be *"unlikely to achieve optimal invisibility, but is a start down the radical direction, for computer science, away from attention on the machine and back on the person and his or her life in the world of work, play, and home"* [21].

Information Appliances as described by Norman [14] have been with us for some time now and their number is increasing. Today, many people own more than one device. Besides traditional computers like desktop PCs or notebooks, they use computers for home entertainment, powerful smartphones and other mobile devices like tablet PCs as well as special-purpose devices like music-players or e-book readers. Computer devices even enter their clothes and bodies as biomedical or special purpose communication devices. As the number of devices grows, so does the need to exchange information and mediate interaction between them. People increasingly express their frustration about the lack of integration between devices and see the need for network standardization and connectivity [20]. While some of the technical interconnectivity problems have already been tackled by different industrial groups like Digital Living Network Alliance (DLNA) [3], others are still open. Of particular interest are changing patterns of use.

Computers are used today in more varying contexts than ever before, ranging from highly structured work to more ad-hoc use of independent, simple tools. They are used in work settings as well as for leisure activities. Computers are, in addition to serving as tools, means of communication and interaction. Some of them just emerge as media in the strongest sense, bridging into rich application worlds. When it comes to information and entertainment usage, the general purpose computer in many cases has been replaced or at least augmented by specific computing devices. Movies are watched and books are read via special computer devices like Blue-ray players or e-book readers, or computers act as cloud devices for public as well as personal media content.

If users control more than one computer, they have to look into issues of whether and how different devices should be and can be connected. This also involves the technical realization of high-speed, high-bandwidth interconnections, but even more so questions of usage patterns, user requirements and user behavior.

Naturally, different devices have different capabilities. Mobile phones for example have computing and storage power that exceeds recent personal computers. They are often considered as very personal items and are always available. Not only are contacts, private photos or calendars being stored, but smartphones also give access to a variety of services. Moreover, as a result of improved wireless interconnectivity, smartphones are often connected to the

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Internet permanently, making them a premier point of access to data stored in the cloud or being used as IO-devices to interact with other systems. As they can be carried around and identified uniquely, they may even serve as tokens indicating the location and even the identity of the user. A wide variety of location-based services has been suggested and many of them have been implemented [8]. The underlying assumption is that the location of the user is an important part of the user's context.

Not only mobile phones but all devices should be able to connect to each other as all devices have their advantages and disadvantages compared to other devices, e.g., with respect to display size and resolution, presentation capabilities or input modalities. Cross-device interaction (XDI) may help to overcome these obstacles through interconnection and seamless integration of different devices in a predefined or ad-hoc manner.

This contribution is structured as follows: first, we will discuss our understanding of XDI and the relation of XDI to current computing paradigms. From this analysis, we derive a definition for XDI and propose a taxonomy to classify different XDI scenarios. Then, we relate examples of XDI in the literature to this definition and discuss how they fit into our understanding of XDI and the taxonomy.

II. CROSS-DEVICE INTERACTION

In environments where humans interact with multiple devices, the term cross-device interaction (XDI) has often been used to describe the underlying interaction paradigm but without a proper definition. This can be problematic as there is no consistency in how the term XDI is used by different authors and in varying application contexts. For example, it is used to describe different forms of interaction with multiple devices [5, 9, 13, 15, 16] or menu navigation [24] up to simple synchronization of history between multiple devices [1, 18, 19]. Even within the areas of those examples, the use of the term differs severely. Therefore, we propose a more structured definition of XDI.

In most cases, when we deal with computers, we are quite aware of the devices that we interact with. A common approach for interaction is Direct Manipulation, where input and output processing meets in a close and consistent regulation loop [7, 17]. Gesture-based approaches, e.g., interacting in front of public or shared displays [12] or using multitouch devices, try to close the gap between input and output.

However, there are certain situations where users can take advantage of non-direct interaction, e.g., if output devices are spatially separated from users or do not offer interfaces between each other, it is hard to interact with them at all. Users can get handicapped by devices if they are not familiar with the input modalities. Also, handling private data can be problematic, if the interaction device is publicly accessible. Not all devices are capable of displaying every type of media like audio, images, videos, 2D- or 3D-objects and thus the information sometimes has to be visualized by specialized devices. In all these examples, it can be helpful or even necessary to interact with other devices available in the spatial context, which are enabled for certain media or certain kinds of interaction modalities. These are typical situations where XDI is required.

In the following, we will clarify the term cross-device interaction in order to give a better understanding of the concept and to prevent misunderstandings.

A. Devices

XDI takes place between devices. It is important to explain our use of the term in order to be able to limit the scope of XDI. Generally, we have three classes of devices: input-, output- and mixed-devices.

Input devices take any form of user input in order to pass control signals onto application systems for further processing or execution. Depending on the device modality, there are different subclasses to refer to. We are talking of mainly visual, sensor, auditory and haptic input devices. Visual input devices consist for example of person-, gesture-, or eye-trackers and pointer-based input. Sensor input devices also track users, but with a multitude of different sensors, despite the mentioned ones. Auditory input devices react to auditive input and haptic devices react to grasp or touch input, e.g. tangibles or touchscreens. Input devices provide the communication interface to computers and act as controllers. Here, the actions of a user are passed on to the computer, processed in applications and the result is usually passed on to output devices. The user either interacts directly with the input device itself, e.g., with mouse, keyboard and touch-input or from a distance, e.g., with trackers or speech-input.

Output devices render and present any kind of information. The output itself can take place in any form that human senses are able to perceive. This ranges from visual to haptic or auditory feedback that the user is able to interpret and can also be multimodal. Common output devices are displays, printers or sound systems but they can also create physical movements such as motors or vibrators or distribute materials like water [2] or even odors.

Mixed devices incorporate both input as well as output, within one device. Combined with processing units, they can act as stand-alone devices. Touch-screens, especially multitouch tables, smartphones or tablet PCs for example belong to the class of mixed devices. Although personal computers consist of different input and output hardware like mice, keyboards, monitors or sound systems they are often perceived as one coherent integrated sensomotorical system by their users.

Apart from this classification, devices can be of different nature to the user. Here, we especially consider the ownership and access of devices.

The *ownership of devices* will be an important factor for XDI settings as it has an impact on the content and the collaboration potential of a particular setting. We see three basic situations:

- *Personal:* Devices that belong to a specific user and are configured and used only by him or her can be seen as *personal devices*. They are potentially carried along and can then be used as a unique token to access user specific settings and content. Another important aspect of personal devices is that owners are usually quite familiar with the handling and the specific interaction techniques of their device. For this reason it may be beneficial to incorporate well handled personal devices in the design of interaction scenarios instead of unfamiliar ones.

- *Group:* If the person belongs to a group or explicitly invites others to share the device, we will call them *group devices*, whereas groups may have different meanings, e.g., memberships or ad-hoc pairing.

- *Open:* When devices can be used by anyone who can access the space, we will call them *open devices*. Those devices do not have a specific owner.

The *access to devices* is depending on the location and the context in which devices are used within XDI. We distinguish between three forms of use of devices:

- *Private:* If a device is controlled by and displays for exactly one person, we will call this private access. This person is the only one interacting with them and his or her actions and information cannot be observed directly by others.

- *Public:* If a device displays for more than one person, but is still controlled by only one person, we speak of public access. However, observers other than the owner will not be able take direct influence into the actions or to the information displayed.

- *Shared:* The third option includes several people who take part in the interaction through a certain device. If at least two persons have access to and control the same device, we speak of shared access.

B. Interaction

The question arises how interaction in XDI scenarios differs from other kinds of interaction with multiple devices. In order to delimit XDI from other forms of interaction, some rules must be provided. We extracted distinctive features of scenarios proposed in different research papers. Then we examined these features from an HCI perspective with regard to the following aspects. How do humans interact with devices within each scenario, e.g., whether a device is touched or just looked at? What kind of relation do devices establish between each other, e.g., input, output, distributed interfaces?

For a typical XDI scenario, we assume that a user directly and consciously uses an input device to manipulate content on some output device. This stands in contrast to systems in ambient environments that may track users and get implicit feedback from them. With XDI input and output take place on different devices, independent of being mixed devices or separated input and output devices.

When we speak of XDI, we presume that a user indirectly interacts with an output device. He or she uses input devices within his or her reach in order to control output devices. We will not use the term XDI when input and output take place on the same device (mixed device). A desktop computer system with mouse and display for example could be seen as a simple form of XDI, because a peripheral input device is used to manipulate a separate output device. A tablet PC in contradiction has no periphery and utilizes direct manipulation right on the display, which also functions as output device. Thus, we only focus on scenarios where input and output devices are from a user's perspective separate from each other.

Within XDI, input is closely connected with output. That means that commands executed over an XDI system will create an immediate and explicit response and the user is able to perceive feedback to the action on the target systems without noticeable delay (cf. Direct Manipulation). This does not necessarily apply to the output time characteristics of the controlled media itself, which can be delayed, e.g., when rendering takes longer.

C. Crossing and Distance

Devices and interaction are closely linked with each other. The interaction within XDI happens across all kind of input, output and mixed devices and not only on some specific device itself. This involves devices like tablets, PCs, smartphones, TVs, presentation computers or even smart items or objects. As our interaction criteria show, XDI is a kind of *proxemic interaction* between devices where users are located inside some well-defined or user perceived activity space. Within this space, users may connect and use devices with different capabilities in order to utilize features for varied presentation, handling or manipulation of information. The response to input is linked with visible, audible or otherwise perceptible output. Therefore, input and output devices have to be situated in such a way that the user can perceive the results of the action immediately. We do not distinguish between rooms, but between activity spaces, e.g., because the disposition of devices and furniture inside rooms determines activity spaces. It is important to point out the interaction and user-centered focus of XDI. Therefore, XDI is bound to explicit sensomotoric feedback, e.g., applications with feedback on a functional or application level are not in the scope of XDI.

III. XDI AND KNOWN COMPUTING PARADIGMS

Many researchers have been concentrating on computing paradigms like ambient computing, ubiquitous computing, pervasive computing and cloud computing. Several aspects of those paradigms are influencing XDI. In the following, we will discuss relations between XDI and these current computing paradigms.

A. Ambient Computing.

Within ambient computing, the environment observes and tracks the users and their actions with the help of sensors

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and reacts either explicitly but mostly implicitly like anticipated by the users (or the developers). As in the vision of ubiquitous computing, computers are integrated in the environment and reside in the background, even more so, they do not show up at all as they are not meant for direct interaction. XDI can benefit from ambient computing from being more aware of the activities of its users and devices. It can be helpful to know about the context of a user, which is relevant for information retrieval or to know about his or her environment. This allows, for example, that devices in reach can be located or information to be linked to previous activities. Here again, XDI requires explicit interaction with devices and also explicit response of systems.

B. *Ubiquitous Computing.*

The vision of ubiquitous computing, as already discussed, includes the omnipresent availability of computers that are preferably not distinguishable from everyday objects. In conjunction with ubiquitous computing, Weiser talked about "calm technology", where technology resides in the periphery, playing a non-dominating role in a user's life [23]. The general availability of devices and computing power is important for XDI, but here, the perception of devices plays a major role. As outlined before, we are still in Weiser's Phase I of ubiquitous computing, and within our XDI settings people consciously use devices that are in their main focus in order to control remote devices.

C. *Pervasive Computing.*

Pervasive computing is often used in conjunction with or even synonymous for ubiquitous computing, although it is not the same. Pervasive computing deals with the connectivity and interfacing of participating devices within a network. This is basically a technical point of view [10]. Pervasive computing provides a technological background of seamless network infrastructures, which is important for XDI, while XDI itself is concerned about the interaction of humans with their devices.

D. *Cloud Computing.*

"Cloud Computing refers to both the applications delivered as services over the Internet and the hardware and system software in the datacenters that provide those services" [4]. Cloud computing provides data consistency among different devices and the users gain flexibility as they are able to access their data anytime from different locations. This also supports unplanned activities, e.g. in *ad-hoc situations* [1]. XDI also benefits from an omnipresent availability of data. Handling multiple devices needs access and consistency of information distributed among all participating devices. What cloud computing does not cover, is the interaction of users with multiple devices. XDI has its focus on interaction with information, whereas cloud computing defines storage, accessibility and data services.

As can be seen, XDI references all of these computing paradigms. It can be seen as a method to access information and interact with endpoints in each paradigm. Furthermore, XDI may be a way to create additional personal interfaces for environments that would normally rely on implicit interaction only. This could help users to reach a better understanding of their surrounding environments.

IV. A TAXONOMY FOR CROSS-DEVICE INTERACTION

Our research helped to identify important distinguishing features that delimit XDI from other forms of interaction with multiple devices. In the following, we summarize our understanding of XDI as outlined in this paper by presenting a definition and a taxonomy for classifying different scenarios of XDI. Our definition of XDI is based on this proposition of a discriminatory subset of distinguishing features as mandatory criteria.

- *Direct Interaction with Input Devices:* The interaction with an input device in order to manipulate content on output devices.
- *Mediated Interaction:* The use of an input device in order to control separate output devices.
- *Perception of Output Devices:* Devices have to be within an activity space of a user that connects multiple devices within an area of perception.
- *Immediate and explicit Feedback:* Users get an immediate explicit response on their commands and are able to see and regulate feedback to the action on the target systems without noticeable delay.

Resulting of our research and reflection above, we define XDI as follows:

Cross-device interaction (XDI) is the type of interaction, where human users interact with multiple separate input and output devices, where input devices will be used to manipulate content on output devices within a perceived interaction space with immediate and explicit feedback.

Within this definition, there are various possible scenarios of XDI.

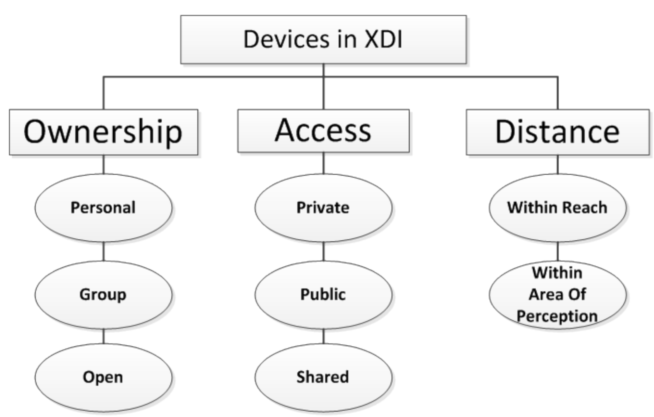

Figure 1. Taxonomy for XDI devices

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To address more detailed characteristics we present a first taxonomy that focuses on attributes of devices: ownership, access and distance (Figure 1). These attributes can be used for further characterization of XDI scenarios.

V. XDI IN THE LITERATURE

After we defined XDI and provided some further refining criteria and parameters in the preceding section, this section will present related work in the field of XDI. The term XDI has often been used in conjunction with many kinds of communicating devices, while the form of interaction has not always been stated clearly [6]. Some work also uses the term XDI, but is difficult to categorize. We outline some approaches that give more detailed information about certain XDI approaches within the field of private and public spaces, ad-hoc situations, control of multiple devices, task continuity and web-history and classify them in terms of our understanding of XDI. This serves to test the robustness of our definition and clarify the boundary to other concepts.

A. Case 1

Schmidt et al. [15] introduce XDI as a solution to several problems when using mobiles and multitouch tables. They identify some issues in connection with the use of multitouch-tables and propose six input attributes for interaction as solutions. Thereby, they target the six problems concerning data transfer, personalization, user interface composition, authentication, localized, private feedback and input expressiveness. Their approaches are based on the identification of mobile phones, some combined with touch-input. Within their scenarios, they fulfill the given mandatory criteria for XDI. There are at least two devices involved, as the interaction always takes place between mobile phones and multitouch tables. The interaction of the user and the system feedback are explicit and immediate and the user is always in line-of-sight with the output device. Their scenarios are good examples for XDI within private, public and shared spaces as well as using personal and group devices. Personal devices are used as secure input devices for public displays. For example, passwords can be entered by selecting the password field on a multitouch-table with a mobile phone, typing the password concealed from others into the designated field on the mobile and transferring it back to the multitouch.

B. Case 2

A system that utilizes Personal Digital Assistants (PDA) to control applications running on other computer systems is realized in the Pebbles project by Myers et al. [13]. One of the applications implemented within Pebbles is the SlideShow Commander. With the SlideShow Commander, one can control PowerPoint presentations given with desktop or laptop computers from one's own PDA. One can not only move forward and backward in the presentation, but also scribble on slides images presented on the PDA, while annotations are shown on the presentation for the audience. Another interaction opportunity is given by the fact that the user can switch between different applications on the presentation device from his handheld computer. In principle, it is possible to use SlideShow Commander in collaborative settings, where different members of the audience take turn in controlling the application or share annotations. This setting also inherits all mandatory criteria for XDI. One device is used to control a presentation platform that is nearby and visible to the user, whereas the given feedback reacts immediately to the users input.

C. Case 3

Among the interesting topics in the field of XDI are ad-hoc situations. Depending on the situation, XDI can either happen within a static environment with fixed devices or ad-hoc, when people meet coincidentally in unknown environments or like to connect personal devices such as mobile phones with devices in these environments. Devices form new constellations when brought together that influence how they are used. Gellersen et al. [5] observe situations with interaction across devices where *"spontaneous interaction enables users to associate their personal devices with devices encountered in their environment"*. They want to facilitate remote interaction with unknown devices, public displays as well as data exchange between mobile devices. Their RELATE interaction model supports the discovery of devices and services within sight in the near environment and proposes the connection of mobiles with those devices. A major topic they discuss is the identification and discovery of participating devices within the immediate environment of a user. In our sense, their work is located in the field of XDI insofar as their design supports the use of mobile devices in ad-hoc situations in order to control other nearby devices with the help of direct manipulation techniques, e.g., pick-and-drop for transferring objects between computer or eSquirt *"a point and click technique for metaphorical squirting of data from one device onto another"*. Unfortunately, they do not give hints about the responsiveness of output devices.

D. Case 4

Another example for XDI is discussed by Kimman et al. [9]. They discuss a design-study for a remote control, which can also be seen as residing within the field of XDI. The remote is used to manipulate multiple different output devices in order to reduce the number of input devices. They use explicit input to control spatially separated devices. This is a borderline case in terms of our classification as it is not quite clear whether the output devices are within area of perception and give immediate feedback.

E. Case 5

Approaches where several devices are coupled to present one input and output area, as done by Schmitz et al. [16] for mobile phones, are difficult to interpret and classify. From a technical point of view their system shows a kind of XDI. Multiple devices can connect in ad-hoc situations and one device can be used to manipulate content seen on another in real-time. Seen from an HCI point of view, the intention of using multiple devices in order to build one large mixed device eliminates the use for XDI as there is only one logical device left to communicate with. If anything, this system has to be categorized as a borderline case of XDI.

F. *Case 6*

Yin and Zhai initiate an instant messaging communication to display menu choices during phone conversations with an interactive voice response (IVR) system [24]. Their work is interesting for XDI insofar, as they interact directly with a mobile phone to navigate through a menu displayed on a remote computer. Their interaction also causes immediate and explicit feedback. The proposed system is a good example of XDI, although the user controls a remote system (IVR). The important aspect here is that the feedback is perceivable on a nearby device, the user's PC.

G. *Case 7*

There is also other work that seems to be located in the field of XDI, but does not meet our definition. Studies of Sohn et al. from Nokia Research [1, 18, 19], for example, show research in the field of continuous workspaces or web-migration. They deal with access to information at different locations with different devices. Users are enabled to browse web pages with one device and proceed with their work later on another device, based on their web-history. While there is communication between devices involved, important criteria for XDI are missing. The distance between user and output device as well as the response time to the user's interaction does not matter in their case. It is possible to use a device and pick up the work later at any time, any place on another device. Here, devices are not used to control other devices, but to synchronize information between them.

H. *Case 8*

Marquardt et al. [11] explore cross-device interaction in a setting of co-located users interacting collaboratively across handheld devices and using those with wall-mounted displays. Their research focuses on interaction techniques that leverage the spatial relationship between people that are interacting with each other as well as proxemics of devices used in their application. The presented interaction techniques aim to ease manipulation of digital information across nearby federated devices and thereby meet our definition of XDI on a general level. There is a slight difference in the basic setting that incorporates collaborating users. From our point of view, this is not a limitation but rather a broader understanding of XDI. At this moment we consider scenarios starting on a personal input device, ending on another nearby output device, independent of any other user at this endpoint. There may be other users and they are affecting XDI but only as an influence and not as a protagonist in such interaction scenarios.

These eight cases delivered an insight into the broad understanding of cross-device interaction that motivated us to clarify and refine the term.

VI. CONCLUSION AND FURTHER WORK

So far, the term cross-device interaction (XDI) has been used quite often, but a clear and consistent definition is still lacking. In this paper, we have proposed a basic definition for XDI. Our taxonomy contributes to delimit the realm of XDI by introducing the dimensions of ownership and access. Our work furthermore allows classifying or constructing different scenarios within this scope in a user- and interaction-centered manner. We exemplify our approach by examining eight cases of potential XDI use found in the literature. We have shown that our taxonomy is widely and practically applicable. However, some special cases that could not be classified properly have shown that there is still potential to further refine the definition and taxonomy.

In our own work, we make use of this definition to guide our investigation of novel ways to make use of the increasing availability of computing devices. For example, we have developed a system for location-centric access and control of presentation systems with the help of personal mobile devices. We have furthermore developed an electronic whiteboard application for collaborative work in shared activity spaces. Work is ongoing of accessing this whiteboard with personal mobile devices as well. Last but not least, we have introduced frameworks for contextualized computer systems as well as media delivery and manipulation on a wide range of devices, from personal mobile devices to open public displays. We refrained from describing these systems in detail since our focus in this contribution has been set on the taxonomy and definition.

In the future, we will further investigate different scenarios of use in the context of cross-device interaction. We expect our definition to evolve to take both the empirical evaluation of our own research systems as well as new literature into account. Our hope is that the taxonomy proposed will help to clarify the research questions involved and to distinguish XDI as a field of research that is distinct, but has close connections to other HCI research areas.

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Indoor localization Using a Magnetic Flux Density Map of a Building

Feasibility study of geomagnetic indoor localization

Dries Vandermeulen, Charles Vercauteren and Maarten Weyn
Faculty of Applied Engineering - CoSys-Lab
University of Antwerp
Paardenmarkt 92, B-2000 Antwerp, Belgium
charles.vercauteren@uantwerpen.be, maarten.weyn@uantwerpen.be

***Abstract*— The need for indoor localization has become increasingly important in recent years for a number of applications. Magnetic flux density fluctuations, caused by reinforced concrete or metal objects, are common in indoor environments. Originally, these fluctuations were considered to be harmful for localization because they can cause electromagnetic interference in sensitive sensors like a compass. However, in many papers it is suggested that these interference patterns can be mapped and used to achieve indoor localization. During this research, tests were performed to determine how feasible geomagnetic indoor localization is for a handheld smartphone device. Pattern matching, a technique often used by radio-frequency based localization technologies, will be used to determine the position of such a device. Advantages of this technology are discussed and possible obstacles are exposed.**

Keywords - Indoor localization; Pattern matching; Magnetic flux density; Geomagnetic indoor localization

I. INTRODUCTION

Since the emergence of the global positioning system, outdoor localization has become a part of our everyday lives. Though the system has proven its worth for outdoor localization in recent years, it falls short when localization is required in an indoor environment, as discussed by Mautz [1]. The ability to locate a person or a device in an indoor environment has become increasingly important for a number of applications.

Since the need for indoor localization systems arose, many technologies have been developed and tested, and it has become apparent there is no overall solution based on a single technology [1]. Studies by Boles and Lohmann [2] and Mouritsen *et.al.* [3] have shown that animals use local anomalies in the Earth's magnetic field to orientate themselves. In recent years, the idea emerged that the same principle can be used for indoor self-localization, termed geomagnetic indoor localization.

Static and low frequency magnetic fields both natural and man-made are present everywhere around us in an indoor environment, as shown by Yamazaki and Keita [4]. The steel reinforced concrete structure of a building and other metal objects cause fluctuations in the Earth's magnetic field. Originally, these fluctuations were considered to be harmful for localization because they can cause electromagnetic interference in sensitive sensors like a compass. However, in many papers it is suggested that these interference patterns can be mapped and used to achieve indoor localization [5] [6] [7] [8] [9] [10].

The goal of this research is to determine how feasible geomagnetic localization is for a handheld smartphone in an indoor environment. Different hardware platforms will be tested, to determine if magnetic flux density measurements are platform independent and localization can be achieved with each platform. This paper wants to validate stated results from other papers using a handheld smartphone.

This paper will first explain the earth's magnetic field in Section II. Second, it will discuss how pattern matching can be done using this magnetic field in Section III. Afterwards, it will describe the used hardware and address the problem of hardware variances in section IV. Section V and VI describe the core of this paper; the indoor magnetic flux density and fingerprinting. In Section VII, interference of objects is discussed and tested. The last part includes the localization measurement model in Section VIII followed by test results in Section IX. The paper in concluded in Section X.

II. EARTH'S MAGNETIC FIELD

Earth's magnetic field originates from currents produced by highly conductive liquid iron spinning inside the outer core. The magnetic field that originates from these currents is called the magnetic B field. The magnitude of the magnetic B field over a surface is described as magnetic flux density and is measured in weber per square meters Wb/m^2, tesla T or gauss G ($1\ Wb/m^2 = 1\ T = 10000\ G$). In this research, tesla is used, as it is the current official unit defined by the SI system. The magnetic B field itself can be affected or distorted by natural or manmade objects that cause interference. The magnetic B field at the earth's surface ranges from 25 to 65 µT.

Magnetic flux density can be measured by a magnetometer to determine magnetic north. It is important to note that magnetic north is not the same as true north. True north or geographical north is the direction the North Pole is located along the earth's rotational axis. Magnetic north refers to the geomagnetic pole position which is not located along the earth's rotational axis. The angle between magnetic north and true north is called magnetic declination.

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Magnetic declination can differ from place to place and changes over time.

Earth magnetic field is described by seven parameters. The total intensity *F* consisting of a north *X*, an east *Y* and a vertical *Z* component. The horizontal intensity *H*, which consist only of the north *X* and the east *Y* components. Inclination *I* describes the angle between *H* and *F*. Declination *D* describes the angle between magnetic north and true north.

Antwerp, the city where this investigation took place has a positive declination of 0° 19', an inclination of 66° 25' and an average magnetic flux density of 48.73 µT. These values can be found using Google maps.

III. GEOMAGNTIC PARTERN MATCHING

Pattern matching is a technique that incorporates measurement data to overcome the cumulative error of an estimated position, as shown by Weyn [11]. While this technique is often used in radio-frequency (RF) based localization technologies, it is very suited for geomagnetic localization, as shown by Storms [5].

The pattern matching process consists of two phases: an offline calibration or training phase and an online tracking or localization phase. During the offline training phase a database is build, containing measurements of the magnetic flux density at predefined positions in a building. This database is called the fingerprint as it is often unique for each building. These measurements will serve as reference points during the localization phase. During the localization phase, the currently measured magnetic flux density by a smartphone is compared to all measurements stored in the fingerprint database. If the current measurement matches a measurement in the fingerprint database it is highly probable that the user will be at the position that corresponds to this fingerprint measurement. Using statistical algorithms the most likely position can be determined.

IV. MAGNETOMETERS

Magnetometers are capable of measuring the three components of earth's magnetic field (x, y and z), relative to their own spatial orientation. Today magnetometers are standard sensors in almost every smartphone, which makes them suitable candidates to use for localization.

For this research two magnetometers on two different platforms were used. A Honeywell HMC5843 3-axis digital compass on a Shimmer 9 dimensions-of-freedom Kinematic Sensor [12]. A AK8973 3-axis magnetometer used on a Huawei Sonic U8650 smartphone [13]. The behavior of each individual sensor was tested to determine if measurements are platform independent.

The first test was conducted in an indoor bedroom apartment were both sensors were individually placed on a wooden table, away from any possible interference factors like metal objects or electronic devices. The sensor would send data back via Bluetooth to a computer were all data was recorded. Both sensors were placed on the table facing true north, which was found using outdoor reference points and Google maps.

Table 1 shows the average magnetic flux density of the first test. Test results show that magnetic flux density measurements are not the same for both sensor platforms. This can be expected, both sensors each have a unique electronic and metal composition, which might distort sensor readings. These distortions are called hard iron effects and are caused by the internal structure of the sensor [14]. Compensation for these hard iron effects is needed. If no compensation for hard iron effects would be done and we use a different sensor for both offline training and online localization phase, we might have an inconsistency between the 2 data sets. Thus, compensating for hard iron effects is crucial for geomagnetic indoor localization.

TABLE 1. SHIMMER SENSOR AND SMARTPHONE AVERAGE MAGNETIC FLUX DENSITY OF STATIC TEST

	Shimmer Sensor	**Smartphone**
x (µT)	-1.05	0.50
y (µT)	7.34	19.19
z (µT)	-57.61	-41.50
Norm (µT)	58.09	42.32

Hard iron characteristics can be found by rotating the sensor round the x, y and z axis. If no hard iron effects are present, rotating a magnetometer 360 degrees and plotting the resulting data as y-axis versus x-axis, will result in a circle centered around (0, 0). Figure 1 and 2 show the resulting circles of the x-y rotation of the smartphone and the Shimmer sensor before compensating for hard iron effects and after. Table 2 shows the compensation values for each axis of both sensors.

TABLE 2. HARD IRON COMPENSATION VALUES FOR BOTH SENSORS

	Shimmer Sensor	**Smartphone**
Correction X (µT)	15.00	3.67
Correction Y (µT)	7.25	0.16
Correction Z (µT)	-11.25	4.52

After compensating both sensors for these hard iron effects by subtracting the compensation values from the raw data, the first test was repeated and the results are shown in Table 3. We can now see that both sensors give very similar measurements at the same position.

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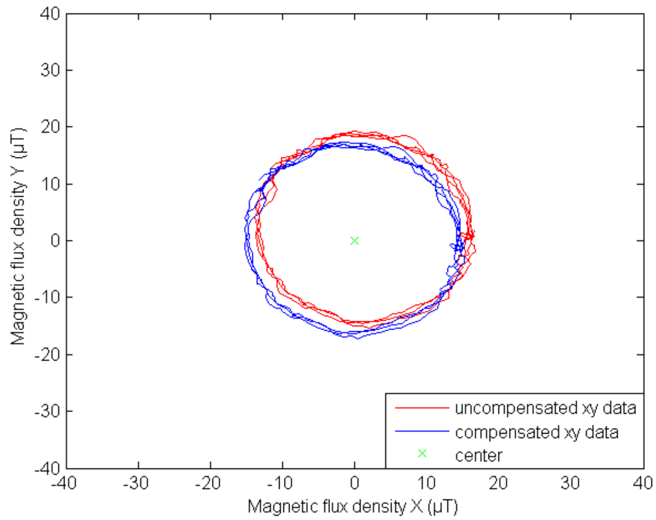

Figure 1. Smartphone hard iron compensation

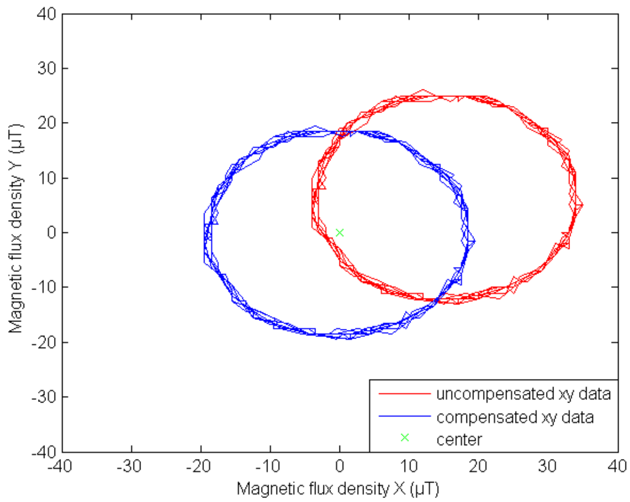

Figure 2. Shimmer sensor hard iron compensation

TABLE 3. SHIMMER SENSOR AND SMARTPHONE AVERAGE MAGNETIC FLUX DENSITY OF STATIC TEST AFTER HARD IRON COMPENSATION

	Shimmer Sensor	**Smartphone**
x (μT)	-0.33	-0.8
y (μT)	17.12	18.01
z (μT)	-45.97	-44.46
Norm (μT)	49.06	47.98

Often, magnetometers are also calibrated to compensate for the presence of external metal or electronic distortions, called soft iron effects. For this research, this is an undesired calibration as the goal of geomagnetic localization is to measure and map these distortions.

If we do not look at the previous test data, we would expect the smartphone to have a higher variance because of its more advanced electronic composition, which might influence the sensitive magnetometer. The test showed that the shimmer sensor had a slightly larger variance, which was unexpected. Additional tests were conducted were all receivers of the smartphone were turned on in an attempt to maximize the variance. Table 4 shows the magnetic flux density measurements of the smartphone with receivers disabled and enabled. Note that the Bluetooth receiver was enabled in both scenarios as it would send back the data. Although variance in the data rose slightly when both receivers were activated, it would not significantly affect our measurements.

TABLE 4. SMARTPHONE MAGNETIC FLUX DENSITY VARIANCE TEST RESULTS

	Wi-Fi and GPS disabled		**Wi-Fi and GPS Enabled**	
	Mean (μT)	Std	Mean (μT)	Std
x	15.07	0.47	15.14	0.48
y	2.35	0.43	2.43	0.54
z	-32.94	0.49	-32.91	0.55
Norm	36.31	0.50	36.32	0.56

As the focus of this research will be handheld smartphones, tests were conducted to see if human hand contact would significantly affect measurements. During the offline calibration phase measurements might be taken with or without contact by a human hand. Magnetic flux density measurement were taken with and without contact by human hand and results are presented in Table 5. The test results show that there was no significant change between both scenarios.

TABLE 5. SMARTPHONE MAGNETIC FLUX DENSITY VARIANCE TEST RESULTS

	No Human Hand Contact		**Human Hand Contact**	
	Mean (μT)	Std	Mean (μT)	Std
x	14.33	0.55	14.48	0.48
y	1.21	0.50	0.93	0.55
z	-33.80	0.52	-33.32	0.52
Norm	36.74	0.54	36.35	0.51

V. INDOOR MAGNETIC FLUX DENSITY

While indoor environments pose good candidates for indoor geomagnetic localization, magnetic flux density measurement must be stable over long periods of time. Li *et. al.* [7] conducted experiments were indoor magnetic flux density was measured in different environments. The results show stable magnetic flux density measurements over a 24 hour period. The experiments were repeated 3 months later and no significant chance was detected.

To achieve indoor localization, it is important that magnetic flux density measurements change considerably from position to position. If the magnetic flux density measurements do not change considerably, the fingerprint might not contain enough information to overcome the cumulative error of the estimated position and indoor localization cannot be achieved [1].

A dynamic test was performed to see if magnetic flux density measurements would vary inside two hallways. The Shimmer sensor was placed on an office chair and was elevated to a height of 1.2m. This height is similar to a user holding a smartphone. The elevation also made sure there was as little interference as possible from the chair itself.

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The chair was moved at a constant velocity (0.3 m/s) through the hallway. The speed is not always constant as human error is inevitable. The first hallway was expected to have changing measurement value because of the reinforce concrete floor and metal furniture in the rooms next to the hallway. The second hallway was expected to have less varying measurements because of the wooden floor and the absence of metal furniture.

Figure 3 and Figure 4 show the measurements of the x, y and z components taken through the first hallway and the second hallway respectively. The test results show changing magnetic flux density measurements for hallway A. These peaks and drops in magnetic flux density allow us to identify certain areas inside the hallway and accordingly allow for localization. The measurements of hallway B tell a different story, there are no peaks or drops to identify certain areas, which makes accurate localization improbable.

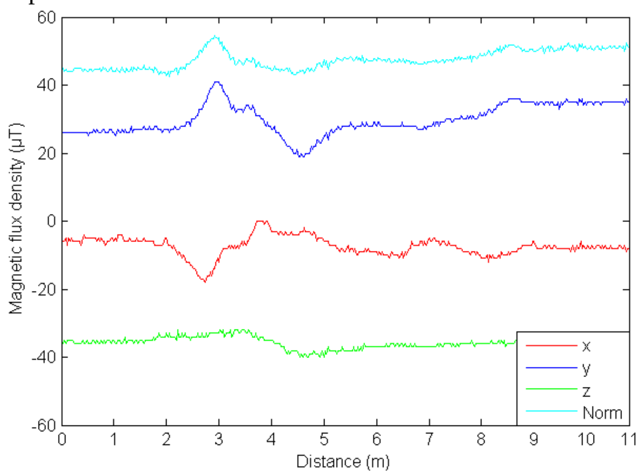

Figure 3. Magnetic flux density dynamic tests of hallway A

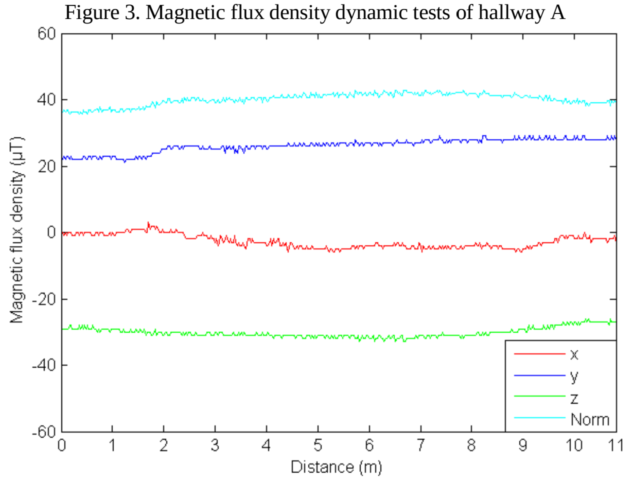

Figure 4. Magnetic flux density dynamic tests of hallway B

VI. INDOOR MAGNETIC FLUX DENSITY FINGERPRINTING

As stated before, pattern matching will be used to achieve indoor localization. This technique requires the recording of a magnetic flux density fingerprint. During this research, an application is developed that allows a user to record such fingerprint. The user loads a map of the desired location in the application. The application will then define measurement positions at the selected resolution. The user selects a desired position, then walks to the coordinates of this position with the magnetometer and starts recording a desired amount of magnetic flux density measurements. It is important that the orientation of the magnetometer does not change during the fingerprinting process as the magnetometer will measure magnetic flux density relative to its own orientation. When all positions are measured, the fingerprint is finished and can either be exported for analysis or used for localization.

The application was used to record a fingerprint of 3 different locations: the ground floor of a suburban house (14 x 16 m), the second floor of a city centered apartment (9 x 12 m) and the second floor lab of the university campus (6 x 19 m). These locations were chosen because they represent different distinct environments were indoor localization might be required. It was important that all locations had multiple rooms and had a medium to large size (+20 m2). Figure 5 shows the recorded fingerprints of the suburban house. The color map shows the magnetic flux density measurements of the normalized x, y and z components taken at 1 m spacing. Areas that remained white were places were no fingerprint measurement could be obtained because of built in cabinets, wardrobes or other furniture.

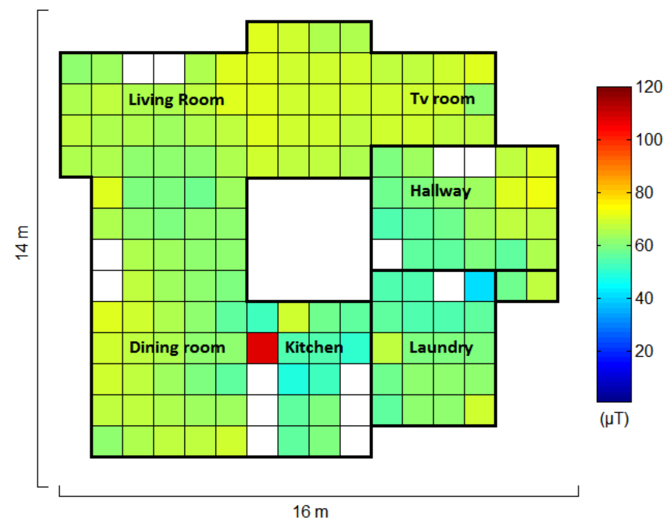

Figure 5. Magnetic flux density fingerprint ground floor suburban house. A big metal stove was located between the dining room and the kitchen. A high magnetic flux density was measured at that location (red square)

The fingerprint in Figure 5 shows that the magnetic flux density characteristics change from position to position. A test was done to determine if these characteristics are unique for an indoor environment. A fingerprint was taken of a garden (4 x 6 m) and a small part of a street (5 x 15 m). Figure 6 shows the obtained fingerprint of the street. The outdoor results are very different from the indoor results. The magnetic flux density characteristics don't change significantly with position. Tables 5 and 6 show the magnetic flux density standard deviation of the recorded measurements for both the indoor and the outdoor fingerprints. The indoor environments clearly have more varying measurements that the outdoor environments.

TABLE 5. MAGNETIC FLUX DENSITY STANDARD DEVIATION OF RECORDED INDOOR FINGERPRINTS

	Suburban house	Apartment	Lab
x (µT)	5.70	5.49	6.99
y (µT)	4.63	5.52	4.84
z (µT)	5.11	4.65	8.08

TABLE 6. MAGNETIC FLUX DENSITY STANDARD DEVIATION OF RECORDED OUTDOOR FINGERPRINTS

	Garden	Street
x (µT)	1.45	3.53
y (µT)	1.28	3.30
z (µT)	0.55	2.65

VII. METAL AND ELECTRONIC OBJECT INTERFERENCE

Indoor environments are places where objects are often moved or replaced. When objects are moved after the initial fingerprinting phase, they can cause undesired inconsistencies between the fingerprint data and real word circumstances.

Tests were conducted to investigate these interferences. Three objects were tested, a perforator, a mobile phone and a hard drive. These objects were chosen because they can represent normal household objects which are often moved within an indoor environment. These different size objects were moved at a constant speed towards a Shimmer sensor to investigate the range and magnitude of the interferences. Figure 6 shows the results of the hard drive test. Magnetic flux density changes drastically as the hard drive moves closer to the sensor. As can be expected the change in magnetic flux density was less significant for the smaller objects. Table 7 shows the interference range of all objects.

Test results show that the size and magnetic composition of the object determines the range and magnitude of the interference. Small size objects only caused interference at a maximum range of ±15 cm, while larger objects cause interference at ±25 cm. While small objects have a negligible influence for a room sized environment, the interference of larger objects cannot always be ignored.

TABLE 7. METAL AND ELECTRONIC OBJECT INTERFERENCE TESTS RESULTS

	Perforator	Phone	Hard Drive
Average velocity (cm/s)	1.48	1.66	1.37
Start of interference (s)	29	24	23
Interference range (cm)	12	15,1	23,5

Fingerprint tests were conducted to confirm these findings. A fingerprint was taken from a small bedroom (3.5 x 3.5 m). Magnetic flux density measurements of the x, y and z component were taken at 0.5 m spacing. Figure 7 shows the interior setup of the room and the resulting magnetic flux density fingerprint of the normalized x, y and z components. As can be seen form this fingerprint, the two speaker cause a clear magnetic flux density interference pattern. The size of this distortion is rather large as speaker are often constructed with strong magnets inside them. After taking the first fingerprint one of the speakers was moved to a different location within the room and a new fingerprint was taken. Figure 8 shows the new interior setup and the resulting new fingerprint. The interference pattern of the moved speaker is clearly visible in the new fingerprint. These test results give an example of how the repositioning and removal of objects inside a room can form an obstacle for indoor geomagnetic localization. When the interior setup of a room changes significantly, a new fingerprint should be taken.

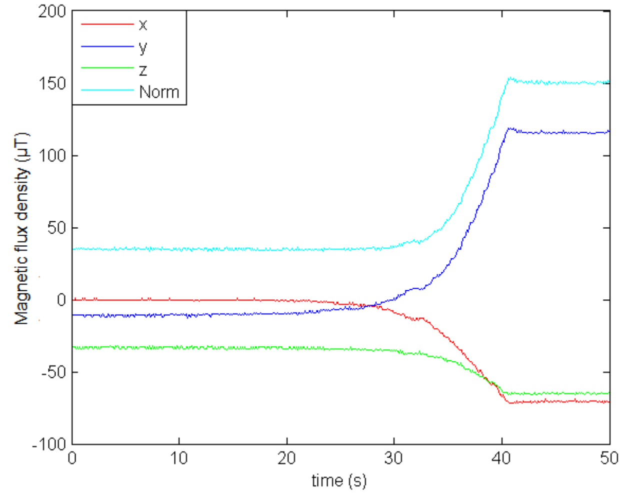

Figure 6. Metal and electronic object interference tests of the hard drive

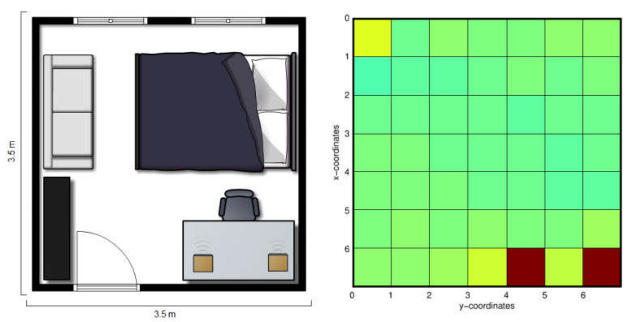

Figure 7. Magnetic flux density fingerprint of bedroom (speaker on original position)

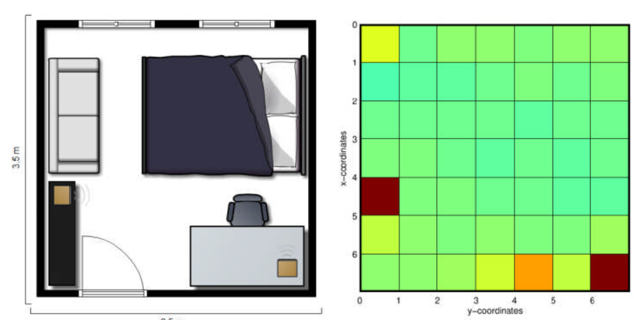

Figure 8. Magnetic flux density fingerprint of bedroom (speaker on new position)

VIII. GEOMAGNETIC INDOOR LOCALIZATION MEASUREMENT MODEL

All previous results suggest that magnetic flux density measurements can be used to achieve indoor localization. It is important to note, that the quality of the localization often depends on the number of measured components that can be used as reference points [1]. Having many values to compare can obviously increase the chance of finding the right position. The number of components that can be recorded by a magnetometer is rather small. Only the x, y and z components of the Earth's magnetic field can be measured. There are some practical considerations to be made during the localization and fingerprinting phase to use these three components.

As stated before, a magnetometer will measure the magnetic flux density components relative to its own orientation. So, to use the three components requires that the orientation of the sensor is exactly the same during fingerprinting and localization phase. This is a requirement that cannot easily be met. A user will walk around in different directions and the orientation of the device will follow along with him. The way the user holds the device is also never the same. Determining the orientation of the device will be key to using all three components. If no information is available about the orientation of the device in either one of these two phases, we can only use the normal of the measured x, y and z components. This would bring the amount of components to be used for localization to only one.

To resolve this issue, a tilt compensated magnetometer can be used [14]. Such magnetometer uses accelerometers to detect the vertical orientation of the device by measuring the force of gravity. Tilt compensation will allow us to calculate the z component of the magnetic field. Using tilt compensation allows us to use two components, the z component and the norm of the x and y component [7]. To use all three components the horizontal orientation of the device needs to be known. To determine the horizontal orientation the magnetometer can be used as a compass. A compass can determine the direction of the magnetic north and can thus determine the horizontal orientation of the device. However, to do this the user has to manually point the device to a reference point on the map e.g. true north. By defining a reference point the horizontal orientation can be determined [11]. This research showed that indoor environments can cause interference in compass measurements. These interferences are called soft-iron effects. Compensation has to be done to remove these interferences to get an accurate heading [14]. It is important to note, that when soft-iron compensation is done, there needs to be clear distinction between the compensated data and the raw data. Orientation requires soft-iron compensation while localization requires no soft-iron compensation.

All aforementioned information can be combined to define a measurement model for geomagnetic indoor localization. Defining a measurement model can provide a technology interface for sensor fusion systems [11]. Algorithm 1 describes the measurement model. The measurement model is used to find the probability of a position x_t given a measurement z_t.

Although magnetic flux density measurement remain stable over long periods of time, moving metal objects like a lift cause variations in these measurements [7]. These sources of error can cause a mismatch in the magnetic flux density measured at the same position. The accumulated error can be modeled as a Gaussian kernel distribution. The standard deviation of this distribution has to represent the maximum variation that can be expected. The standard deviation was set to 2 µT as this was the maximum standard deviation reported by Li et. al 2 m from a lift [7].

Algorithm 1: Geomagnetic Measurement Model (z_t, x_t)

get z_t^+ from fingerprint for x_t
if $eCompass_{tiltCompensation}$ and $eCompass_{HeadingCompensation}$ then
  $w_x = w_x \,.\, p(z_t^x | \, x_t)$
  $w_y = w_y \,.\, p(z_t^y | \, x_t)$
  $w_z = w_z \,.\, p(z_t^z | \, x_t)$
else if $eCompass_{tiltCompensation}$ then
  $w_{xy} = w_{xy} \,.\, p(z_t^{xy} | \, x_t)$
  $w_z = w_z \,.\, p(z_t^z | \, x_t)$
else
  $w_{norm} = w_{norm} \,.\, p(z_t^{norm} | \, x_t)$
end if
$w_{total} = w_x . w_y . w_z . w_{norm}$
return w_{total}
with:
$p(z_t | \, x_t) = \frac{e\,(\Phi_{Measurement} - \Phi_{fp})}{2\sigma^2}$ σ = 2 µT

IX. GEOMAGNETIC INDOOR LOCALIZATION FEASIBILITY RESULTS

The measurement model defined in Algorithm 1 was used to investigate the feasibility of geomagnetic indoor localization. To test the feasibility, each individual fingerprint position and its accompanying magnetic flux density measurements was used as a test position. Each test position was compared to all measurement positions in the fingerprint using the measurement model described in Algorithm 1. The measurement model would give a high weight to fingerprint positions that had magnetic flux density measurements similar to the test position. The weight represents the likelihood of the user being at position x_t given the measurement z_t. The final estimated position x_t was calculated as the weighted average of all fingerprint positions [11], using Equation 1. Positions with a high probability will contribute more to the final estimated position.

$$x_t = \frac{\sum_{i=1}^{N} w_t^i x_t^i}{\sum_{i=1}^{N} w_t^i} \tag{1}$$

The coordinates of the final estimated position are compared to the real coordinates of the test position and the error is stored. The process will be repeated for all measurement positions within the fingerprint. The maximum, minimum and average errors for every location were determined. The amount of estimated positions that were within 1 m and the amount of estimated positions that were in the same room was also determined. Table 8 shows

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the results that were obtained from the three fingerprints that were recorded.

TABLE 8. GEOMAGNETIC FEASIBILITY RESULTS

	Suburban house			Apartment			Lab		
Components	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Avg (m)	4.8	4.3	3.1	3.7	3.3	2.5	4.5	3.4	2.5
Min (m)	0.1	0.0	0.0	0.1	0.1	0.0	0.2	0.0	0.0
Max (m)	9.3	9.4	8.8	7.2	7.4	7.0	10.5	11.3	11.8
< 1m (%)	4	9	17	7	13	23	9	20	32
room (%)	10	18	44	21	31	49	73	74	82

It is clear from the results that using three components gives the best localization results and results deteriorate as fewer components are available. The maximum and minimum errors stay relatively the same for all amounts of components. All localization results were combined to form a cumulative density function in Figure 9.

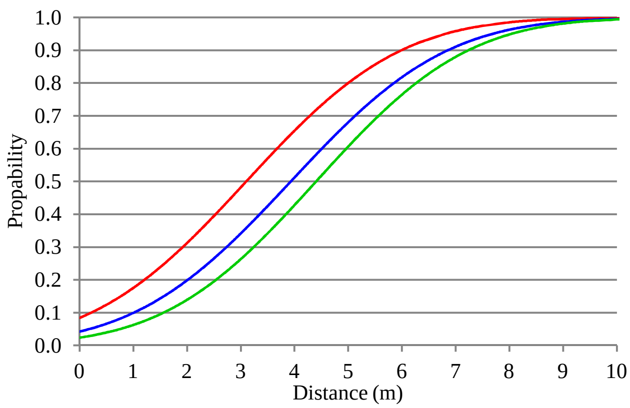

Figure 9: Cumulative density function, error of localization using 3 (red), 2 (blue) and 1 component (green).

Table 9 shows the results of the same test, only now the room of the test position was known. Only measurement position in the same room as the test position would have to be compared to test position. Test results were significantly better, even using only one component could achieve localization close to 1 m. These results indicate that geomagnetic localization might be more suited for localization within a room.

TABLE 9: GEOMAGNETIC FEASIBILITY RESULTS WHEN ROOM WAS KNOWN

	Suburban house			Apartment			University lab		
Components	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Avg (m)	1.4	1.0	0.8	1.4	1.0	0.6	2.2	1.4	0.9
Min (m)	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Max (m)	3.2	2.8	2.3	5.2	3.9	2.1	5.4	5.2	3.7
< 1m (%)	30	47	67	35	50	74	21	42	61

Figure 10 shows the cumulative density function when the room was known.

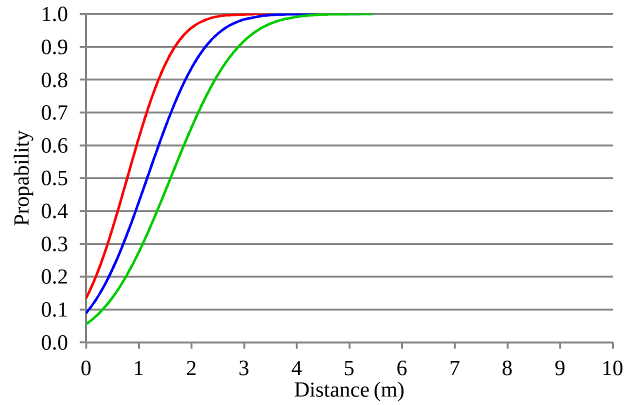

Figure 10: Cumulative density function, error of localization using 3 (red), 2 (blue) and 1 component (green) when the room was known

Although previous results give a good indication of how feasible geomagnetic indoor localization can be, they are largely theoretical. To verify these findings, a more practical test was done. A route was recorded through the suburban house. On this route, magnetic flux density measurements were taken at the same position where fingerprint measurements were taken. The position could not be exactly the same as human error is inevitable. Figure 11 shows the recorded magnetic flux density for the route and the fingerprint.

The results show that the recorded measurements are not exactly the same. The average correlation coefficient between the route and the fingerprint x, y and z measurements is 0.93 which means that both recordings are very similar. The recorded route was estimated within the environment using Algorithm 1. Figure 11 shows the original route (blue) and the estimated route (red). First the route was estimated when nothing about the room was known, later when the room of the measurement was known. Table 10 shows the localization results of both scenarios.

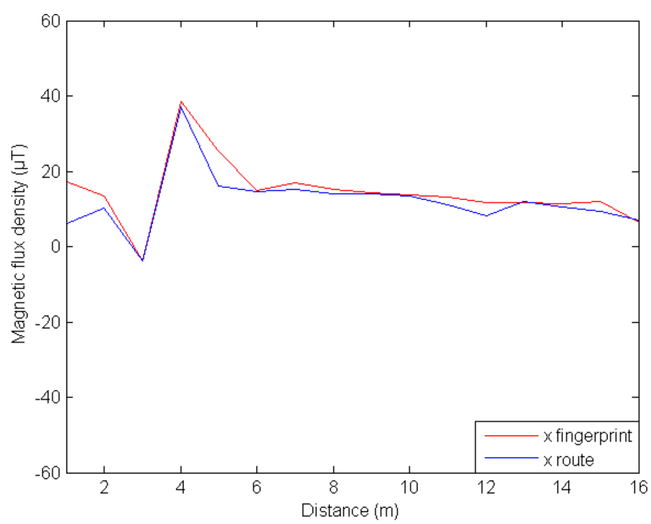

Figure 11: Magnetic flux density x measurements from fingerprint and route

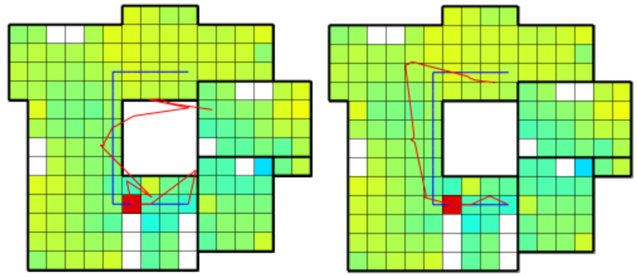

Figure 12: Suburban house route results for 3 components when room was not known (left) and when the room was known (right), blue line is the recorded route and red the estimated route.

TABLE 10: ROUTE ESTIMATION RESULTS

	Global			Room known		
Components	**1**	**2**	**3**	**1**	**2**	**3**
Avg (m)	2.1	2.1	1.4	1.3	1.1	0.9
Min (m)	0.2	0.1	0.0	0.0	0.0	0.0
Max (m)	4.22	4.2	4.5	3.1	2.6	2.0
< 1m (%)	13	13	38	43	43	62
room (%)	25	31	56	/	/	/

This practical test confirmed the original findings. Localization is very dependent on the amount of components that can be used and results are superior when room sized localization is required.

X. CONCLUSIONS

Geomagnetic localization has some big advantages compared to other indoor localization technologies. No dedicated hardware infrastructure is needed, as magnetic fields are present all around us. Magnetic flux density measurements are platform independent as long as hard-iron calibration is applied. Magnetic flux density measurements remain stable over long periods of time. Magnetometers are build-in sensors in almost every smartphone on the market which makes them very suited as a localization sensor.

During this research, many test have been performed to determine how a magnetic flux density map can be used to achieve indoor localization. Possible obstacles are exposed and theoretical feasibility results were produced. Test results show that the quality of localization is strongly depended on the number of components that were used. When three components are used, geomagnetic localization performs reasonably well. When only one or two components are used the feasibility results decrease rapidly. Although these results might not be sufficient for a standalone technology, geomagnetic localization can be applied in a sensor fusion system. A sensor fusion system combines all available sensor measurement data on the platform to estimate the position of the user. Results were poor when global localization was needed but showed promising results when the room was known. In a sensor fusion system other more suited technologies might be used for global localization while geomagnetic localization can be used to determine the most likely position within a room.

While this research touches on many aspect of geomagnetic localization, further research is still required. Using the three components of the Earth's magnetic field is crucial to achieve proper localization results. To use these three components in a real life localization application, a tilt/heading compensated magnetometer must be developed. Determining the maximum variance of such a magnetometer of such a magnetometer under all circumstances is crucial.

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Classification of Driver's Head Posture by using Unsupervised Neural Networks

Momoyo Ito
Institute of Technology and Science
The University of Tokushima
Tokushima, Japan
momoito@is.tokushima-u.ac.jp

Kazuhito Sato
Faculty of Systems Science and Technology
Akita Prefectural University
Akita, Japan
ksato@akita-pu.ac.jp

Minoru Fukumi
Institute of Technology and Science
The University of Tokushima
Tokushima, Japan
fukumi@is.tokushima-u.ac.jp

***Abstract*—Many car accidents are caused by deviations in driver behavior. We aim to construct a driver assistance system that is able to detect such driver deviations. The system detects deviation using time-series head motion information. We analyze driver's head posture during safety verification at an unsignalized intersection with poor visibility and propose a method for classifying head posture using two types of unsupervised neural networks: Self-Organizing Maps (SOMs) and fuzzy Adaptive Resonance Theory (ART). The proposed method has a feature based on the hybridization of two unsupervised neural networks with a seamless mapping procedure comprising the following two steps. The first step is to classify the input patterns in feature space using one-dimensional SOMs with a non-circular mapping layer. The second step is to integrate the weight vectors of the one-dimensional SOMs into appropriate categories using fuzzy ART networks. The proposed method can generate the optimal number of cluster-generated labels for the target problem. We experimentally assess the effectiveness of the proposed method by adjusting the fuzzy ART network vigilance parameters. In addition, we indicate that driver's head posture during safety verification can be categorized according to their individual properties.**

Keywords-driving behavior; head motion; SOMs; fuzzy ART

I. INTRODUCTION

Recently, driver assistance systems, which deal with a driver's state and detect if drivers are able to continue driving safely, have become increasingly popular. Many researchers have been studying the detection of driver's gaze movements and sleepiness for the estimation of unsafe driving. Cognitive errors and faulty decisions cause many traffic accidents, and the primary error factor is believed to be continual deviation from normal states. We hypothesize that head motion patterns of a driver can be used for verification of safe driver conditions by detecting deviations in such motion patterns due to inattentiveness. This study aims to construct a driver assistance system that is able to detect such deviations. Recently, active safety technology designed to prevent car accidents has been drawing significant attention. There are a number of technologies that detect drowsiness or inattentive behavior using driver's eye-gaze line or head turning motion information to alert drivers of potentially dangerous situations [1]-[3]. Active safety technology is currently available in some automobiles. However, such systems only detect a single instance of deviation from normal conditions, such as inattentiveness. Our system continually analyzes time-series data to generate a predictive driver deviation signal.

Our system quantizes driver's 3D head motions during safety verification behavior using only phase variation of 2D images taken by an in-vehicle monocular camera and modeled head motion information. In this study, we analyze head postures of a driver during safety verification at an unsignalized blind intersection and propose a head posture classification method using two types of unsupervised neural networks: Self-Organizing Maps (SOMs) [4] and fuzzy Adaptive Resonance Theory (ART) [5]. In addition, we discuss face orientation categorization using the proposed method.

The remainder of this paper is organized as follows. Section II describes related work. An analysis of safety verification is presented in Section III. The proposed method is introduced in Section IV and experimental results are presented in Section V. The conclusion and future work are presented in Section VI.

II. RELATED WORK

The highest number of reported traffic accident fatalities involves pedestrians. From automobile-focused analysis of pedestrian fatalities, the Traffic Accident Research and Analysis Center has announced that 83% of accidents occur when driving a vehicle in a straight direction. In such cases, "inattentive driving," e.g., looking at distant traffic signals or operating audio equipment, and "careless driving," e.g., idly and thinking, equally contribute (35%) to 70% of the total accidents. On the other hand, 70% of pedestrian actions are violations. Seventy-three percent are crossing violations, such as crossing immediately before or after a vehicle, crossing outside crosswalks, and ignoring traffic signals. There is a very high risk of fatal accidents when drivers succumb to inattentive or careless driving, which easily occurs when driving in a straight direction and when pedestrians violate crossing regulations. Here, "careless driving" refers to operating an automobile in a distracted state because of psychological and physiological factors. Drivers operating a vehicle in a distracted state are at risk of not perceiving potential dangers or may demonstrate delayed responses to such dangers. In a distracted state, the driver's mental and physical resources are distributed without focusing on driving behaviors and requirements, which is a

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common contributor to serious accidents [6]. Several studies have examined such distracted states. Homma et al. [7] focused on what they referred to as the vague state, and Abe et al. [8] examined what they referred to the thinking state. These studies promoted the experimental verification of such states and confirmed the existence of characteristic scenes in which discovery delay or oversight of changes in an ambient environment occurs.

The prediction of driver's behavior is effective for the overall prevention of traffic accidents. However, individual driver characteristics are greatly influenced by states of mind, such as emotional stress and mental burden, which are not always constant. Emotional stress is an important factor in traffic accidents; irritability and impatience increase risky driving behaviors, such as short and narrow inter-vehicle distance, rapid acceleration and deceleration, and driving at high speeds. In addition, excessive anxiety generates carelessness or oversight because it interferes with cognitive processes. Matthews [9] stated that the various emotional stresses during driving must be broadly classified into the following three factors. The "degree of involvement in the driving task (Task Engagement)" involves the level of driver engagement and fatigue. "Puzzle-distress (Distress)" includes feelings of tension, pleasure–displeasure, and anger. "Anxiety (Worry)" involves cognitive interference. Individual thresholds for anger or frustration caused by conflict with another car, e.g., the other car does not run as expected, vary for each driver. However, regardless of the different thresholds and tolerances, these emotions exist as stress and affect driving behaviors. In addition, acting within time constraints or delays can easily lead to impatience, e.g., you cannot proceed as intended because of a traffic jam. Such situations can evoke emotional stress. However, driving behavior prediction that considers operating characteristics on the basis of the mental and emotion state of drivers has not yet been realized.

Many researchers have been working on the estimation of drivers' face orientation, head postures, and gaze. S. J. Lee et al. proposed a vision-based real-time gaze zone estimator that works in both day and night conditions and is sufficiently robust to recognize facial image variation caused by eyeglasses [10]. In another system, driver vigilance has been estimated by the percentage of eye closure and a fuzzy classifier using infrared images [11]. Another study focusing on natural driving environments presented an automatic calibration method and categorized the head position using 12 gaze zones with a particle filter [12]. In addition, drivers' head positions have been estimated using localized gradient orientation histograms of the facial region as input to support vector regressors [13]. A robust driver's head and facial feature tracking system, which is capable of detecting occluded eye and mouth features, has also been proposed [14]. These methods use facial orientation, driver's gaze, and the degree of eye openness to estimate the degree of driver's concentration and fatigue; these factors are realized by detecting and tracking the corresponding facial feature points. However, these approaches have some inherent technical issues, such as the failure of tracking and mismatch in the relationship between corresponding facial feature points, because changes in the driving environment lead to different degrees of light. The proposed method does not require the detection and tracking of facial feature points. We focus on time-series information of geometric phase changes in a two-dimensional space captured by a single video camera, with respect to the neutral driving position seated to the fixed position of an individual driver.

III. ANALYSIS OF SAFETY VERIFICATION BEHAVIOR

Most car accidents occur near or in intersections. If safety verifications are insufficient and the driver is operating a vehicle in an abnormal state, the probability of a car accident is significantly higher. In our study, we constructed a safety verification behavior model according to an individual's behavior during safety verification motions at an unsignalized blind intersection. To construct the safety verification behavior model, we quantize head posture changes made during safety verification motions. In this section, we analyze a driver's upper body posture motions during safety verification behavior and discuss the granularity of quantization.

A. Datasets

To analyze a driver's safety verification posture, actual driving environment data were collected. The subject, a man in his twenties, gave informed consent prior to engaging in the driving exercise. The subject practiced driving the designated course before the actual data collection. The course proceeded around the University of Tokushima, and it took approximately 15 min to complete one lap. A monocular in-vehicle camera (Anshin-mini, Anshin Management Co., Ltd., see Figure 1) was set on the windshield in front of the driver's seat. We recorded the subject's upper body data (driver's images). Another camera was set behind the rearview mirror to record images in front of the car (driving scene images). The image resolution was 640 × 480 pixels, and the frame rate was 30 fps. There were some unsignalized blind intersections in the course. The course is shown in Figure 2 (a), and an example of an unsignalized blind intersection is shown in Figure 2 (b). Data were collected on three different days, resulting in three unique datasets: A, B, and C. The subject drove the course

Figure 1. Monocular in-vehicle camera.

once per day.

B. Dataset Analysis

We analyzed right turn behavior at the intersections, as shown in Figure 2 (b). Figure 3 illustrates the subject's head posture changes during safety verification. From dataset A, the subject verified the safety of the intersection with deeply bent head postures. On the other hand, from datasets B and C, the subject made smaller bending movements. From all the dataset results, we were able to recognize a common posture while checking the convex mirrors when entering the intersection. For sufficient quantization of head postures, the classification of frontal facial features, head postures when checking a convex mirror, small head bending postures, deep head bending postures, and right and left checking postures is the minimum requirement.

IV. PROPOSED METHOD

The proposed method has a feature based on the hybridization of two unsupervised neural networks with a seamless mapping procedure comprising the following steps. First, on the basis of the similarity of the spatial phase structure of images, we identify a local neighborhood region containing the order of phase changes. The region is mapped to one-dimensional space equivalent to more than the optimal number of clusters. Labels that match the optimal number of clusters are generated by additional learning that is in accordance with the order of the one-dimensional maps formed in the neighborhood region.

Specifically, SOMs have excellent topological properties for spatial mapping. Using one-dimensional SOMs with a non-circular mapping layer, the neighborhood region can form an independent one-dimensional space that locally maintains order on the basis of the similarity of the structural phase. In addition, after mapping, sparse input data are reflected in the weight vectors of the mapping units. The weight vectors for each unit of the one-dimensional mapping layer maintaining this order are positioned to enter the ART network by sequentially placing them into the ART input space from the start or end of the terminal units. In reality, ART encourages the formation of adaptive category combinations with stability and plasticity to achieve the optimal number of cluster-generated labels for the target problem. Figure 4 depicts an overview of the hybridization of the two unsupervised neural networks. The proposed method has a seamless mapping procedure comprising the following two steps, as shown in Figure 4.

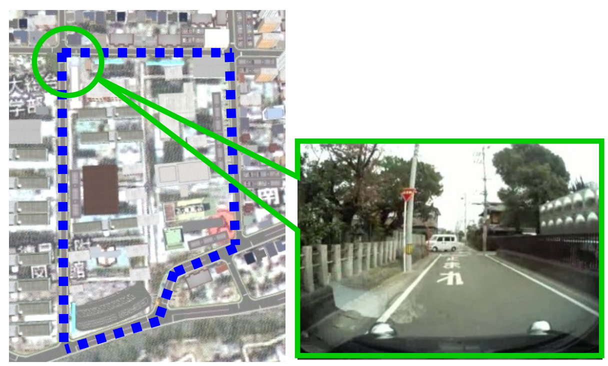
The first step is to classify the input patterns in feature space using one-dimensional SOMs with a non-circular mapping layer. The second step is to integrate the weight vectors of the one-dimensional SOMs into proper categories using fuzzy ART networks.

The algorithm of SOMs comprises the following steps.

1). Let $w_{i,j}(t)$ be the weight from the input unit i to the mapping unit j at time t. The weights are initialized with random numbers.
2). Let $x_i(t)$ be the input data to the input unit at time t.
3). The Euclidean distance d_j between $x_i(t)$ and $w_{i,j}(t)$ is calculated as follows.

$$d_j = \sqrt{\sum_{i=1}^{I} \left(x_i(t) - w_{i,j}(t)\right)^2} \quad (1)$$

4). The winning unit d_j becomes a minimum. Let $N_c(t)$ be



(a) Course map (b) Unsignalized intersection

Figure 2. Driving course.

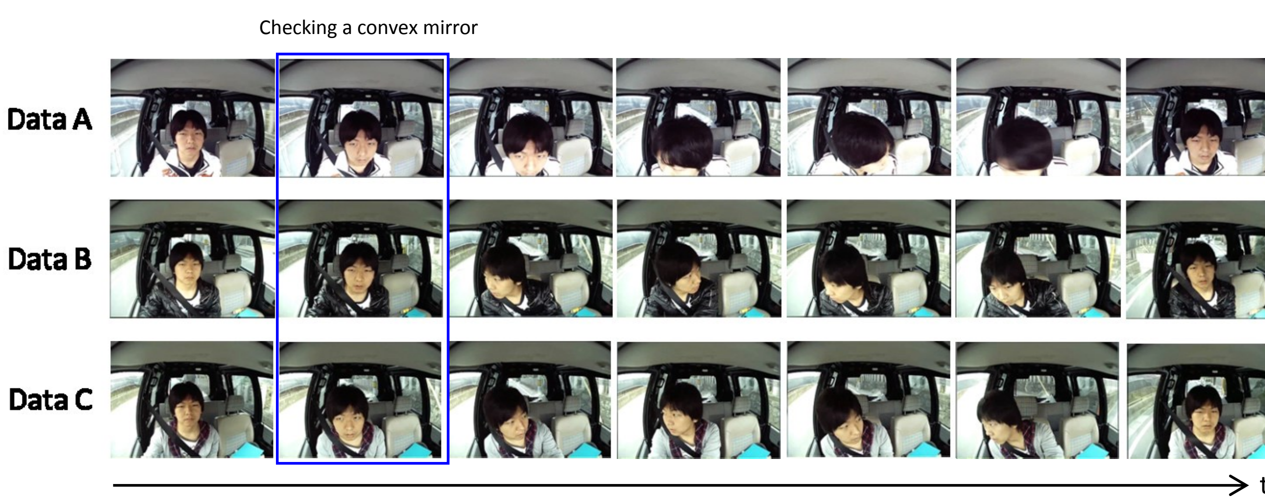


Figure 3. Head posture change during safety verification.

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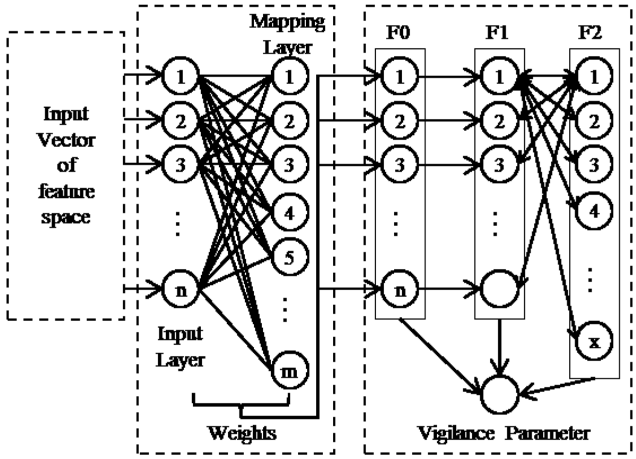
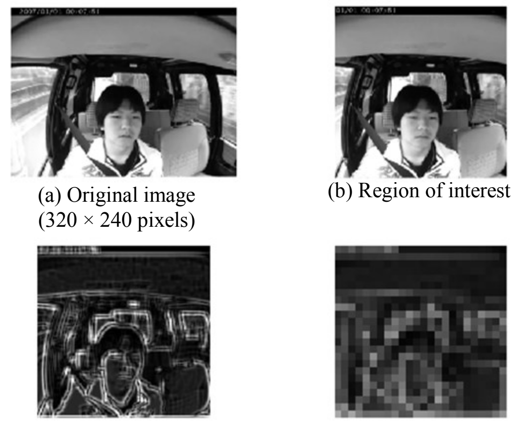


Figure 4. Network structure of proposed method.



(a) Original image (320 × 240 pixels)

(b) Region of interest

(c) Gabor wavelet filter image

(d) Coarse-grained image (24 × 24 pixels)

Figure 5. Input data of SOMs.

the units of the winning unit neighborhood. The weight $w_{i,j}(t)$ inside $N_c(t)$ is updated.

$$w_{i,j}(t+1) = w_{i,j}(t) + \alpha(t)\left(x_i(t) - w_{i,j}(t)\right) \quad (2)$$

Here, $\alpha(t)$ is the training coefficient, which decreases with time. Training ends when the iterations reach the maximum number.

In this study, the initial value of α(t) is set as 0.5, and that of Nc(t) is set as 2/3 of the number of mapping layer units, such that the values decrease linearly with time. The number of learning operations is empirically set as 1,000.

The fuzzy ART algorithm is presented below. Fuzzy ART network architecture consists of the following three fields: Field 0 (F0) receives input data, Field 1 (F1) is for feature representation, and Field 2 (F2) is for category representation.

1). w_i denotes the weights between each F2 i and each corresponding F1. All w_i values are initialized as one.
2). Input data x is the SOM weight $w_{i,j}$ for F0.
3). For each unit i in F2, the choice function T_i is defined as follows.

$$T_i = \frac{|x \wedge w_i|}{a + |w_i|} \quad (3)$$

4). T_c is a winning category, where c gives the maximum value of T_i. The category with the smallest index is chosen if more than T_i is maximal. When T_c is selected for a category, the T_i unit on the c of F2 is set to one and other units are set to zero.
5). Resonance or resetting is assessed. The match function that $x \wedge w_c$ to F1 of the signal from the unit in the c of F2.

$$\frac{|x \wedge w_c|}{|i|} \geqq p \quad (4)$$

Here, x and c are resonant. Resonance occurs if the match function of the selected category meets the vigilance criterion. Then, the weight vector w_{i0} is updated as follows.

$$w_{i0} = r(x \wedge w_{i0}) + (1 - r)w_c \quad (5)$$

If x has no resonance with T_c, then T_c is reset. The network seeks the next category where T_i is maximal and reselects it. The network determines resonance or resets. If all categories are reset, then a unit is created on F2 and a new category is registered. Here, r denotes the learning speed parameter.

The units of F2 and SOM's weight correspond in fuzzy ART. And similar feature is integrated of category.

V. Experimental Results

We examined the effectiveness of the proposed method on the basis of the safety verification analysis.

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TABLE I. CATEGORY INTEGRATION RESULTS (DATASET A)

N: no data mapped to unit

Dataset A		SOMs mapping unit number																								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Vigilance parameter	0.93	1	1	1	1	1	2	2	N	3	3	3	N	4	4	4	4	5	5	N	6	6	6	6	7	7
	0.94	1	1	1	2	2	N	3	3	N	4	4	4	4	5	5	5	5	6	N	7	7	7	7	8	8
	0.95	1	1	1	2	2	N	3	3	N	4	4	4	5	5	6	6	6	6	N	7	7	7	8	8	8
	0.96	1	1	2	2	2	3	3	4	4	5	5	5	6	6	7	7	7	8	8	N	9	9	10	10	11
	0.97	1	1	2	2	3	N	4	4	N	5	5	6	6	7	8	8	9	9	N	10	10	11	11	12	12

TABLE II. CATEGORY INTEGRATION RESULTS (DATASET B)

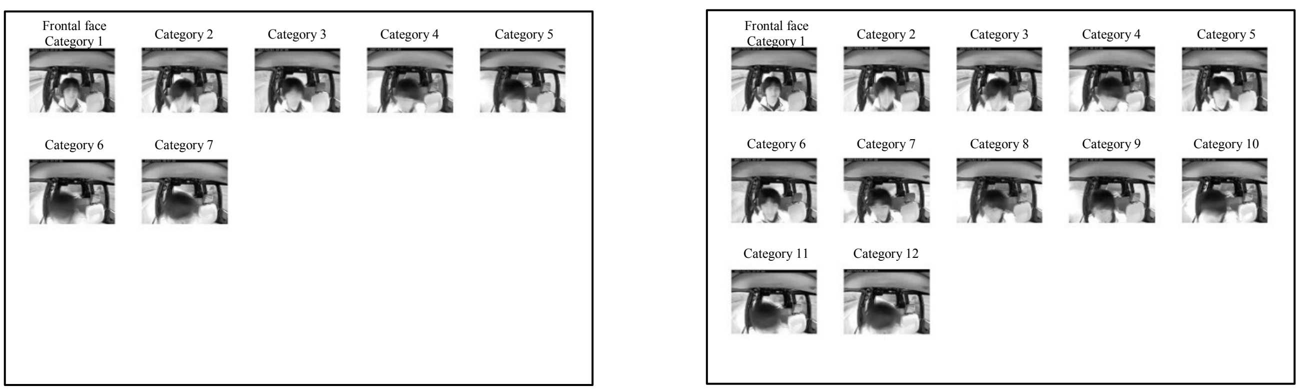
N: no data mapped to unit

Dataset B		SOMs mapping unit number																								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Vigilance parameter	0.93	1	1	1	1	1	2	2	2	2	3	3	3	3	3	4	4	N	4	N	5	5	5	5	6	6
	0.94	1	1	1	1	2	2	2	3	3	3	4	4	4	5	6	N	5	N	7	7	6	N	6	7	7
	0.95	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	N	7	N	8	8	8	7	9	9
	0.96	1	1	1	2	2	2	3	3	4	4	5	5	6	6	7	7	7	N	8	8	9	9	10	10	11
	0.97	1	1	2	2	2	3	3	4	4	N	5	5	6	6	7	8	8	9	9	10	10	11	11	12	12

TABLE III. CATEGORY INTEGRATION RESULTS (DATASET C)

N: no data mapped to unit

Dataset C		SOMs mapping unit number																								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Vigilance parameter	0.93	1	1	1	1	1	1	2	N	2	3	3	N	3	4	4	4	5	5	5	5	6	6	6	7	7
	0.94	1	1	1	2	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6	N	7	7	7	7	7
	0.95	1	1	1	2	2	2	3	3	4	4	4	5	5	N	6	6	6	7	7	7	8	8	9	9	9
	0.96	1	1	2	2	2	3	3	N	4	N	5	5	6	6	7	7	8	8	N	9	9	10	10	11	11
	0.97	1	1	2	N	3	3	4	5	5	6	7	7	N	8	N	9	N	10	10	11	11	12	12	13	13



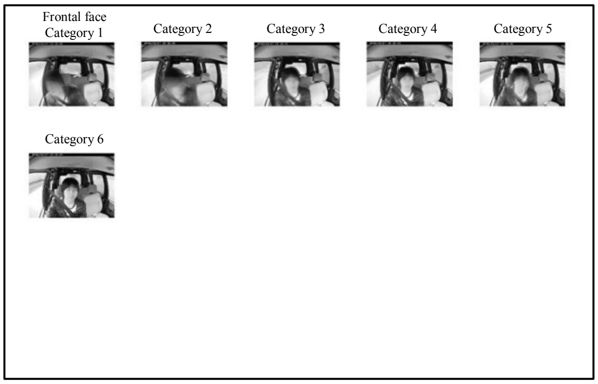
(a) Vigilance parameter: 0.93

(b) Vigilance parameter: 0.97

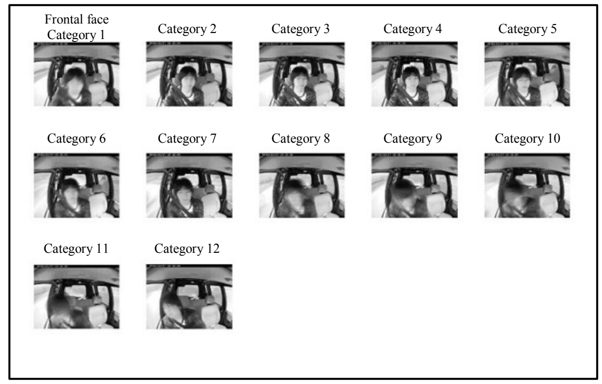
Figure 6. Average image for each integrated category (dataset A)

Datasets A, B, and C were used in this experiment. Figure 5 shows details of the experimental preprocessing. Figure 5 (a) is the original image (320 × 240 pixels). Figure 5 (b) is the region of interest (240 × 240 pixels) extracted from the center of the original image. Figure 5 (c) is Gabor wavelet filter image of Figure 5 (b). Figure 5 (d) is a coarse-grained image (24 × 24 pixels) of Figure 5 (c). The input features of the SOMs are the coarse-grained image pixel values (576 dimensions). We empirically set the mapping layer to 25 units.

The advantage of the proposed method is the ability to adaptively integrate categories of one-dimensional SOM mapping results to maintain neighborhood units by adjusting the fuzzy ART vigilance parameter. Tables I–III show the results for vigilance parameters from 0.93 to 0.97 for datasets A, B, and C, respectively. The SOM's unit number (1–25) corresponds to the category number of the integrated

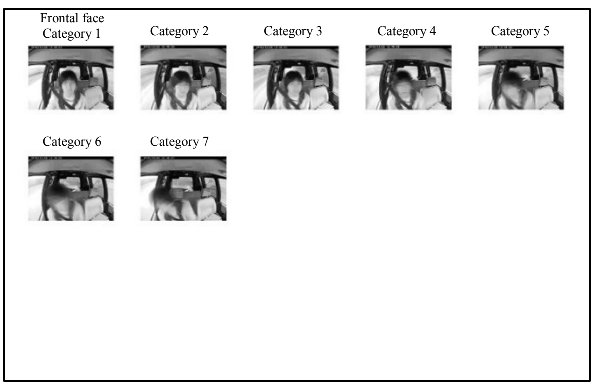


(a) Vigilance parameter: 0.93

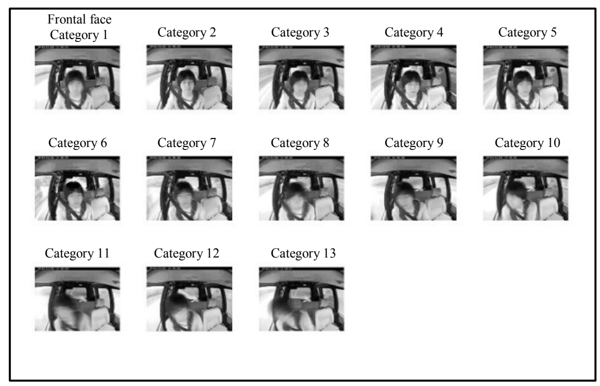


(b) Vigilance parameter: 0.97

Figure 7. Average image for each integrated category (dataset B)

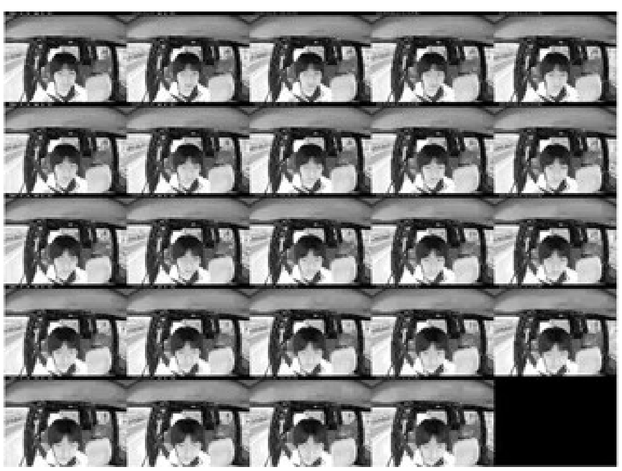


(a) Vigilance parameter: 0.93

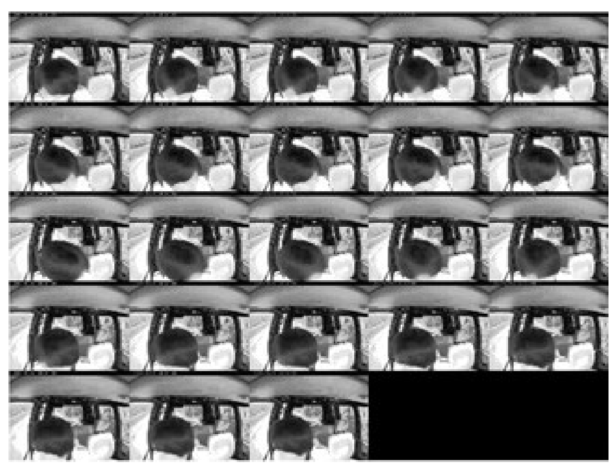


(b) Vigilance parameter: 0.97

Figure 8. Average image for each integrated category (dataset C)



(a) Frontal face category



(b) Deep head bending category

Figure 9. Head posture classification results (dataset A).

result from fuzzy ART. In these tables, N indicates that no data are mapped to the unit. In addition, category integration is achieved with N as the boundary and integration is conducted within the boundary areas. Specifically, focusing on mapping units from 1 to 9 in Table II, similar units are integrated to make a neighborhood as the vigilance parameter decreases from 0.97 to 0.93. When the vigilance parameter is 0.97, units 1 and 2 are integrated into category 1.

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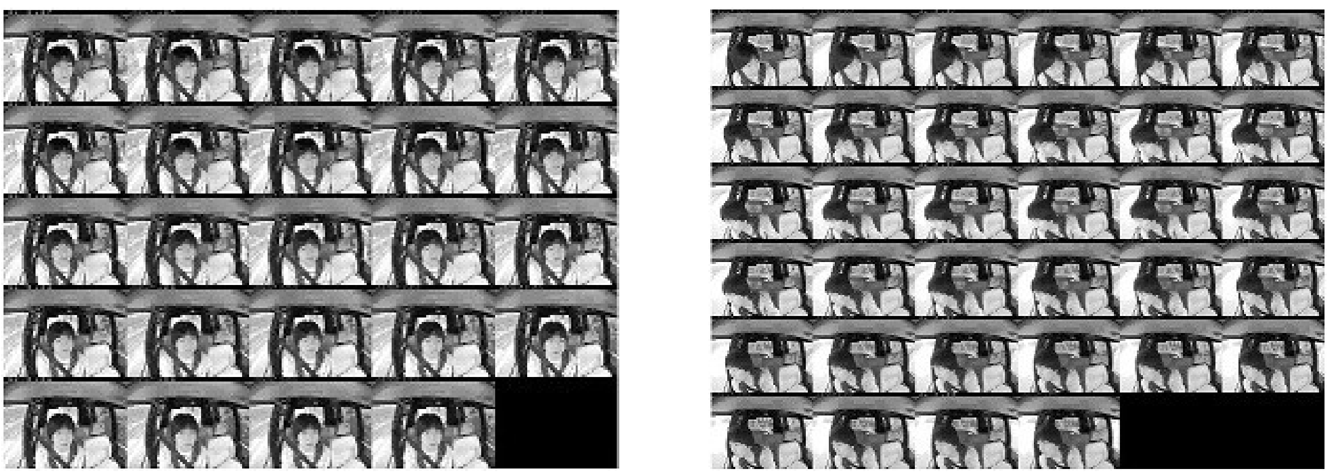
(a) Frontal face category

(b) Small head bending category

Figure 10. Head posture classification results (dataset B).



(a) Frontal face category

(b) Small head bending category

Figure 11. Head posture classification results (dataset C).

Similarly, units 3, 4, and 5, units 6 and 7, and units 8 and 9 are integrated into categories 2, 3, and 4, respectively. In contrast, when the vigilance parameter is 0.93, units 1–5 and units 6–9 are integrated into categories 1 and 2, respectively. As shown in Table II, the boundary unit changes adaptively with the vigilance parameter.

Figures 6, 7 and 8 show the average images from datasets A, B and C, respectively. In these figures, each safety verification posture is ordered according to the phase variation of the images on the basis of the frontal face category. Figures 6, 7 and 8 illustrate that the safety verification motion mapped by the one-dimensional SOMs is integrated with a similar head posture category and that face orientation phases adaptively with the vigilance parameter control. On the basis of the front-facing head posture, Figures 6, 7 and 8 illustrate the results of sorting and quantifying the extent of head posture changes (i.e., geometric phase changes) associated with safety verification behavior. A front-facing head posture represents the neutral driving position seated to the fixed position of an individual driver. The average image in each category is calculated. All captured images corresponding to the safety verification behavior period are classified using our proposed method. Momentary head postures vary according to driving conditions. In particular, left or right head postures due to safety verification in a non-signalized intersection significantly depend on the degree of visibility. In addition, head postures associated with looking into the intersection have been confirmed. By adaptively controlling vigilance parameters, we were effectively able to analyze changes in

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the head posture during safety verification behavior in time-series. When vigilance parameters were set to relatively low values, e.g., 0.93, excessive and abrupt head posture changes during safety verification were captured; however, the proposed method could not guarantee the required classification accuracy for analysis of time-series changes. On the other hand, when vigilance parameters were set to a more appropriate value, e.g., 0.97, it was possible to generate categories that appropriately represent the time-series variation of the safety verification behavior. Furthermore, by considering the safety verification behavior of a single subject at the same intersection and the analysis of datasets on different driving days, the proposed method can adaptively categorize subject-specific safety verification behaviors. For safety verification behavior with the head bending posture, as can be seen in Figures 9 (b), 10 (b) and 11 (b), right and left postures are in the same category because the proposed method quantizes the phase variations of the full region of interest and uses this information as a foundation for categorization and integration.

To sensitively separate right and left head postures and recognize the degree of head bending during safety verification, recursive categorization using the proposed method with a mixed category is expected to be effective.

VI. CONCLUSION AND FUTURE WORK

In this study, we analyzed driver's head posture during safety verification at an unsignalized blind intersection and proposed a method of classifying head postures using two types of unsupervised neural networks: SOMs and fuzzy ART to quantize driver's head motion for the detection continual deviation signals. It was demonstrated that the proposed method was able to appropriately approximate head posture categories for a driver assistance system.

In future, we will recursively apply the results reported here to the proposed method.

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Exergame Design Guidelines for Enhancing Elderly's Physical and Social Activities

Rainer Planinc, Isabella Nake and Martin Kampel
Computer Vision Lab
Vienna University of Technology
{rainer.planinc, martin.kampel}@tuwien.ac.at, isabella.nake@chello.at

***Abstract*—Games based on full-body interaction are able to increase physical and social activity and thus have been evaluated regarding their appropriateness for elderly. Results show that exergames have a positive impact on elderly people, because they help them to remain active and thereby they also contribute to their overall well-being and increased mobility, but most of the existing games on the market are not suitable for them. This work presents design guidelines for the development of exergames which are controlled by body movements and especially considers the requirements of elderly players. Furthermore, these theoretical guidelines are applied to the game FishCatcher, being introduced in this work. Finally, challenges in applying theoretical guidelines to practical games are discussed using the example of FishCatcher.**

Keywords—exergame; elderly; physical activities; social activities;

I. INTRODUCTION

Exergames are computer and video games which are not played sitting in front of the computer or any other monitor, but require full-body movement of the player to control the game [1]. Various input devices for exergames exist, for example exercise bikes, foot operated pads and motion sensors [2]. Two different types of motion input can be distinguished. The first uses a controller for tracking the movements of the player, for example the Nintendo Wii Remote [3]. The player has to move the controller or press buttons which are placed on the controller, or even both at the same time. The second type of motion input does not need any controller, but the games are controlled directly by tracking body movements such as hand gestures. Amongst others, Sony PlayStation II EyeToy [4] and Microsoft Kinect [5] belong to this type of motion sensors. Games using these motion sensors have the advantages that players do not have to pay attention to any controller in their hand, but are able to interact with the game directly, thus resulting in a more simple interaction [6].

Exergames are not only used among children, teenagers and young adults, but they can also be used by grownups and elderly to increase physical activity and motivate elderly to be more active (e.g., [7], [8]). Hence, in the field of Ambient Assisted Living (AAL), exergames offer benefits for elderly and enable them to stay physically fit and thus increase the mobility of elderly. In addition, exergames are also applied to rehabilitation to raise the motivation, since exercises with a high number of repetitions are demanded [7]. Furthermore, elderly people lack in staying physically active [8]. Hence, it is important to boost their physical activity in an entertaining way. The development of systems to improve the quality of life and the well-being of seniors to prevent them from age-related diseases and injuries became more significant [9]. Digital games which are not only designed for entertainment, but for education, training, advertising, research or health as a primary purpose, are called "serious games" [10].

Already during the 1980s, Weisman [11] investigated the benefits of using computer games for elderly people. Those games are exercises to improve the eye - hand coordination as well as memory trainings and they can enhance their self-esteem. Weisman evaluates four computer games that are suitable for elderly people, which means they do not depend on quick hand-eye coordination or speed and have no small moving objects. Since no appropriate commercial games were available, adjustments for the needs of elderly are introduced. Evaluation of the adoptions are performed with residents of a nursing home. 80% of those who were invited were willing to play and demonstrated that also elderly people can have fun playing computer games. Weisman highlights the importance of large symbols, clear auditory clues and the adaptability to the users' skills in computer games for elderly people.

After the Nintendo Wii has been introduced to the market, research on the use and benefits for elderly people is conducted. Wollersheim et al. [1] tested the physical and psychosocial effects of Nintendo Wii Sports games among older women. The result of this study shows particularly the social benefits the game-play has on elderly women. They are better connected among themselves, but also to their grandchildren. Furthermore, the study of Clark and Kraemer [12] is based on the Nintendo Wii, evaluating the change in the risk of falling amongst elderly people playing the Nintendo Wii bowling simulation. After two weeks of playing the bowling game on a regular basis, a decreased fall risk of the patient could be shown. Additionally, Harley et al. [13] organized a Wii Bowling League between residents of different sheltered houses to investigate the impact of Nintendo Wii playing on physical and social activities of elderly people. Therefore, regular playing sessions in small groups of residents of close sheltered houses were arranged together with two public events. The study followed the participants over the first year. At the beginning of the study the players encountered problems with pressing the right button in the proper moment. All of them were focused on the game and while one was using the Wii Remote, the others were watching and giving advices. One year later, this complete concentration on the game was gone. Spending time together was more important than the actual game. The players were talking about everyday problems, eating and drinking besides playing the bowling game. The study shows that the Nintendo Wii promotes physical and social activity. But not only the Nintendo Wii is used for investigating the influence of video games on elderly. Beside one Nintendo Wii game, Shubert [14] tested two other video games for their appropriateness as physical activity for elderly people: Dancetown Fitness System and Sony Playstation II

EyeToy. The results show that those two games are more suited for elderly people since they are easy to use and consider the seniors' requirements. The Nintendo Wii games are typically set up by activity directors, not by the patients themselves. Furthermore, they require too fast movements or contain fast moving objects and the feedback is too negative.

Studies have shown that elderly people enjoy the Nintendo Wii bowling game [13], [15]. However, attention should be paid to their sparse experience with computers. Because of the uncertainty about the handling of new technologies, seniors take up a critical stance towards them and are afraid of making a mistake [15]. In the study of Weisman [11], 20% of the elderly who were invited to play computer games refused to do so because they were afraid of exposing their deficits, another 10% needed encouragement. Furthermore, the participants of the Nintendo Wii bowling events of Neufeldt [15] thought they broke the game, when they pressed a wrong button and an unexpected menu was opened. Beside the Nintendo Wii bowling game, other games (e.g., Dancetown Fitness System [14], SilverBalance [16]) exist which are accessible for the elderly people, but several studies have shown that most of those computer games which are already commercially available on the market are not suited for elderly people [14], [17]. Thus, games which are attractive to a senior audience should be developed. Game developers have to be careful not to think about their interests when creating the game, but the needs and requirements of the target group of these games [18].

Another controller for Nintendo Wii games, besides the Wii Remote, which also initiated a lot of new studies related to the use of video games for elderly people, is the Nintendo Wii BalanceBoard. Gerling et al. [19] conducted a study making use of both, the Nintendo Wii Balance Board and the Wii Remote for game control. It is evaluated how age-related changes, especially cognitive and physical limitations, influence game design for elderly people. The result shows that also elderly enjoy Wii games as leisure activity. Gerling et al. [17] investigated the usability and accessibility of two video games which are controlled with a Nintendo Wii Balance Board for elderly players. The game with a reduced graphical style and the possibility of sitting down during gaming is more appealing for elderly people than the other one. Players perceive better game control and are less afraid while using the board since the simpler user interface increases the focus on body movements and the perceived safety in bodily exertion on the balance board. Based on a case study which uses the Nintendo Wii Balance Board to encourage elderly players to the use of video games, Gerling et al. [16] discusses game design guidelines for developing safe and usable games for elderly people. The major guidelines, which are mentioned in this paper, are: elderly people should be able to play sitting and standing, no extensive or sudden movements should be required, players should be able to adjust the level of difficulty individually and the game should give constructive feedback to avoid frustration. The Nintendo Wii BalenceBoard is also used by Navarro [9], who conducted a study concerning the usage of interactive games to improve the physical and mental well-being of elderly. Therefore, four Nintendo Wii balance games are analyzed. As a result, a design framework is proposed, which contains the following feedback loop: (1) monitoring the current status of the patient, (2) interpretation of this data, (3) adjustments of the trainings plan (if needed), (4) communication back to the patient and (5) repetition of this cycle.

With the launch of Microsoft Kinect, a new technology is investigated regarding its use for elderly people and a new type of gaming concept was introduced. Gerling et al. [6] created guidelines for full-body interaction in games for elderly people. Therefore, they conducted two studies; the first one investigates the performance of a given set of gestures. The results show that traditional gesture movements should be limited for elderly people. Based on those findings, a game was implemented using a Microsoft Kinect for gesture recognition and is evaluated during the second study. It is shown that this game, which uses gestures that are suited for elderly people, has a positive effect on the participants' mood. Borghese et al. [20] developed a low-cost system which can be used for at-home rehabilitation. The goal is to use technologies such as a Microsoft Kinect and a game engine, which contains two mini games, adapts the game level automatically to the patient's status and gives audio-visual feedback, to motivate the patients to exercise. The whole rehabilitation process can be monitored by the hospital. The aim is to build a game which is enjoyable and at the same time useful for therapeutic purposes.

The aim of this paper is to summarize and evaluate design guidelines based on previous studies to be considered in order to develop a multi-player exergame for elderly people, enhancing their physical and social activities. Furthermore, a prototype of the game FishCatcher is implemented according to these guidelines and results are discussed. The rest of this work is structured as follows: design guidelines for exergames are summarized in Section 2, their implementation on an elderly friendly game is shown in Section 3. A discussion of the application of these guidelines and a conclusion is presented in Section 4.

II. Design Guidelines for Exergames

As previous studies have shown (e.g., [14], [17]), already commercially available games on the market are not suitable for elderly people. Evaluation of digital games led to guidelines helping to create an appropriate game for the senior audience. These guidelines evolved from testing and analyzing commercially available games, research studies as well as discussions with elderly people [18]. This section summarizes those guidelines and provides the basis for the implementation of FishCatcher.

1) Mind the physical condition: An important factor to be considered when designing a video game for elderly players based on body movement are the age-related processes, having an impact on the ability to move [6]. Common age-related changes are decrements in posture, balance, gait and fine motor skills, affects on visual and hearing senses as well as impairment of short-term memory, attention and vigilance [19]. Additional aspects to be addressed are longer reaction and overall movement times and the increased risk of fall. Especially the latter has to be respected to avoid unsuitable movements which cause injuries [6].

Due to diseases or injuries of the elderly players, limited use of the extremities and the presence of wheelchairs have to be accounted for. This can be realized by offering gestures

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where the user can either use one arm or both and can be carried out standing or sitting. The range of motion should be evaluated according to the abilities of each individual player. Instead of a high precision of gesture recognition, a bigger tolerance should be claimed. To avoid overexertion and injury, the player should have enough time to relax and recover between physically intense periods [6].

2) Use appropriate gestures: Players should have the possibility to learn the gestures before the actual start of the game in a tutorial [6]. They should become familiar with the technology during training phases. As soon as those trainings are not required anymore, players should be able to skip them [9]. It should not be assumed that players remember different gestures over the whole game period, especially that they can recall the gestures in the moment they are required. This means it should not be necessary that the player performs a gesture to trigger another action, but there should be an in-game event which reminds the player to perform the gesture [6].

3) Avoid small objects: Most existing games, which are currently available on the market, are not suitable for elderly people because they consist of small, fast moving characters and targets which can produce strain and anxiety [11], [20]. It is easier for the elderly to have just one task at the time to deal with and also to play with bigger characters.

4) Give visual and auditive feedback: Unlike young people (so called ”digital natives”), elderly people did not grow up surrounded by computers and video games. Thus, elderly people are not as confident in their ability to use this technologies as the young [21], which causes computer anxiety. To avoid the anxiety, the players should be encouraged by positive feedback and successful experiences. Therefore, it is recommended to give positive feedback on learning goals rather than performance goals.

Players should be able to understand the relation between their movements and the display and the game has to respond according to their movements [9]. They should get feedback so they can learn how to interact with the game. In the case of failure, they blame themselves and not the game, which can lead to a low self-esteem and frustration [17]. As soon as the players finish their tasks or achieve a goal, they should get a positive feedback immediately. They should never get any negative feedback, neither for not achieving a goal nor for not performing an activity [8]. For example, in the project UbiFit Garden [22] the more the player exercises the more beautiful the garden becomes; flowers grow and butterflies appear. If the player does not exercise, nothing happens. There are no flowers growing, but the player does not get any negative feedback.

5) Adjust the difficulty: The goal of the game has to be reachable for the players, so that they keep their motivation and continue playing [9]. Unnecessary cognitive complexity and complex movements should be avoided. Since there is a large range in ability between elderly people, the game should offer the possibility to adjust the difficulty [6]. It is important that more active players are challenged, so that they do not lose their interest in the game and others are not overstrained. The game should not be frustrating, but entertaining [9]. The best way to realize this is to adapt the challenges dynamically. The players should reach a “flow state”, in which a good balance between challenge and the players’ skill level exist [20]. In this state, they are completely focused on the game which might reduce physical pain or hide possible impairments.

For additional motivation it might be helpful to display the users’ previous scores. To become better and beat themselves is an extra personal goal for the players [8].

To keep the game interesting and avoid habituation, especially when playing it regularly, it should contain randomized elements, so that the player has to react slightly different each time [20].

6) Use a clear user interface: Elderly people have no experiences with computer games [6]. To avoid people needing assistance during the game, all instructions should be clear and use common language. Furthermore, no information that is not needed should be included, e.g., additional Graphical User Interface (GUI) elements. All actions should be explained using diagrams or simple on-screen demonstrations. Also, the start-up and shutdown have to be easy, so that neither the older adults nor the nursing stuff need to have specific technical knowledge. The user interface should be easy to use, so that players can focus on the actual exercise [8].

Rules and instructions should also be available as audio [9]. For non-speech audio signals, lower frequencies should be used, since aging might reduce the sensitivity for pure tones and high frequencies [21]. It should be noted that massive in-game sound, in combination with hints and explanations from the assistance or other players, can create stress for the players and result in less fun playing the game [15].

7) Use a suitable topic: The topic of the video game should be adjusted to the interests of elderly people [9]. The participants of the study of [17] made positive comments about the theme of the game, which was related to garden and animals. The entry into the video game world is easier, when the required gestures are related to real-world actions. Seniors prefer games which give them an educational or cultural benefit [18], but they refuse violence in computer games [23].

8) Encourage social interaction: Due to physical disability or other age-related problems, elderly experience social isolation [24]. Video games are one possibility to maintain the relationships with families or friends. Social interaction is an important factor regarding the motivation of elderly people for playing video games [21]. Playing with others who are encouraging and cheering increases the fun [11]. If elderly people start regularly common playing sessions, their social interaction grows. While at the first sessions the main focus is on the game, soon the concentration is shifted to conversations about the game and also about everyday problems. The communication is not only part of the game events, but may also spread into their daily life, for example the playing sessions become a topic of conversation at lunch [15], [13]. Thus, they become closer and get to know each other better [1]. Playing video games does not only encourage the social interaction among elderly people, but also improves the relationship to their grandchildren due to the shared interest and new topic of conversation. Elderly people are pleased to have the feeling to be up to date with their grandchildren and be able to play with them at a later date [13]. The design of a game and its interface which addresses both the older generation and their grandchildren at the same time is an interesting challenge [21]. In the study of [18] elderly people were involved in the design process of computer games. Six out of ten participants designed a multi-player game. Therefore, it is reasonable to design a game that can be played together with others.

III. Implementation of Guidelines: FishCatcher

FishCatcher is an exergame which is implemented according to design guidelines for video games for elderly. In contrast to commercially available games, this game considers the requirements of elderly. Elderly people can benefit from exergames in different ways. First, digital games are a leisure activity. They can be used for relaxation and entertainment. If the game has an accessible design and thoughtfully integrated feedback, it can increase the self-efficacy. Secondly, elderly people can enjoy playing digital games together with others which increases social inclusion and reduces isolation. Not only multi-player games, but also games, which can be played alone, are used as social activity with friends or family. Third, since exergames demand body movements to control them, they help to be physically active [21]. FishCatcher is controlled by arm movements, which are tracked by a 3D sensor (e.g., Microsoft Kinect) and uses the OpenNI library. Arms are tracked using the OpenNI library NITE and tracking is initialized by performing a wave gesture. Visualization of the fish and the surroundings is implemented using OpenGL and blender models.

In this game, yellow and red fish are swimming from left to right and vice versa (see Figure 1). Elderly have to wave with their hands in order for the sensor to recognize them. When this happens, a worm is displayed in front of the hand, in order to directly give feedback about the player's hand position. To catch the fish, the players have to touch them with their hands. If a fish is touched, it disappears and a sound is played, depending on whether a yellow or red fish was touched. Hitting red fish results in a deduction of two points, whereas each yellow fish that was caught yields one point. At no time the score can become negative, in order to avoid negative feedback. The score is represented by stars, where one star corresponds to one point. When a player has collected ten points, a big star is displayed instead of ten smaller ones. The game stores the best five scores and displays them on the menu, so that the players can see their improvement.

One game lasts 30 seconds, and, during this time, the players try to catch as many yellow fish as possible, while avoiding touching the red fish. The remaining time is shown by a small yellow fish at the bottom of the window. When the game starts the fish is located leftmost at the bottom. During the 30 seconds, this fish moves to the right side. After that time, the fish is located rightmost, which signifies that the game is over. After one game is over the users can take a break and decide whether they want to continue playing or not. Furthermore, the player can choose between three different levels of difficulty. The easiest one contains the fewest amount of yellow fish and also of red ones, while the most difficult level consists of the biggest number of yellow and red fish, respectively. Another difference between those three levels is the velocity and the size of the fish. The fish in the simplest level are swimming slower and are bigger than the fish of the most complex level. In the medium level, the numbers of fish, the velocity as well as their size are in between the two others.

Fig. 1. Yellow and red fish are swimming, the stars specify the current score and the little fish at the bottom shows the remaining time

A. Game Modes

The game offers different variants of playing. In addition to the previously described way, the single-player mode, two possibilities of multi-player modes exist, which are described in the following section.

- Single-Player: This way of playing is already described in the previous part. One player tries to catch as many yellow fish as possible while avoiding to touch the red ones. The goal is to receive as many points as possible.
- Multi-Player 1: This variant is similar to the previous one. In contrast to the previous version, in this mode two or more players are catching together the yellow fish. The number of caught yellow fish of both players is added together.
- Multi-Player 2: Also for this mode at least two players are required. One or more players catch all the yellow fish, while the other one(s) catch the red ones. If the score is zero at the end of the game, the players who caught the red fish won; if it is greater than zero, the other players won.

The game FishCatcher, as well as games which were introduced in previous studies, is controlled by hand movements. One reason for using only hand gestures is the high number of elderly people who are unsteady on their feet or sitting in a wheelchair. Since games which are really controlled by full-body movements might increase the risk of falling of those people, it is reasonable when the game can be controlled by hand gestures only and thus be played also sitting. Furthermore, to train arms and hands is also important for daily activities, such as grasping objects or brushing teeth. With exergames, elderly people are not only encouraged to move their arms, but also their coordination capabilities (especially hand - eye coordination) are improved.

B. Exergames Design Guidelines Applied On FishCatcher

Before the start of the development of FishCatcher, studies regarding guidelines, especially in the context of games for elderly and exergames, were analyzed. This section illustrates the integration of those guidelines in the game FishCatcher.

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1) Mind the physical condition: An important issue is to consider the physical condition of elderly, since age-related processes may have an impact on the ability to move. FishCatcher is developed to address as many elderly as possible. Therefore, it is created in such a way, that the players can stand on their feet as well as sit on a chair or in a wheel chair while playing the game. In addition, it can be played using both arms as well as just one of them. Since the fish are swimming from left to right and vice versa, different positions to catch a fish exist. This means that no unsuitable movements are required because each player can decide individually which position is the most pleasant one to touch the fish.

2) Use appropriate gestures: It should not be required that the players have to perform a gesture to trigger another action. In FishCatcher this is avoided, since the fish only have to be touched and no gestures are required.

3) Avoid small objects: Although the size and the velocity of the fish are depending on the chosen level, even for the most difficult level the objects were designed to fulfill the criterion of not being too small or moving too fast.

4) Give visual and auditive feedback: Since it is recommended to provide not only visual but also auditive feedback, a sound is played after a fish was caught and disappeared. The sound is different for red and yellow fish, so that it is possible to use audio in order to be able to differentiate between yellow and red fish. To give positive feedback when users manage to catch a yellow fish, they get a star, which symbolizes one point. Although the players lose points when they touch red fish, they do not get a real penalty since the points never become negative. The worm which is displayed on the hand gives the user the feedback that the hand was recognized by the sensor. If no worm is visible, the hand was not recognized and the user can not catch the fish until the waving gesture is performed so that the sensor recognizes the hand again. Hence, the users are able to understand the relation between their hand movements and the display better.

5) Adjust the difficulty: To be adaptable for different players, no matter if they are active or frail, they can choose one of three levels each time a new game is started. The more active players should be challenged with the difficult level, and the frail ones should not be overstrained with the easy one. To give additional motivation, the best five scores of previous games are displayed. This shows the users if they are getting better after repeating the game several times. To avoid exactly the same movements for each repetition of the game, the size and the velocity of the fish contain random values. Thus, players have to react slightly different each time.

6) Use a clear user interface: The user interface of the game is quite simple so that it is not overloaded with unnecessary elements and the user is able to concentrate on the game. While the game is loaded, an instruction for the game is displayed. On the menu screen, a short description and a simple animation show the players how to move their arms in way that the sensor can recognize them. The current score of the game is not shown as a number, but as stars. To avoid having too many stars displayed at the same time, always ten stars are collected as one big star.

7) Use a suitable topic: To adjust the topic to the interests of elderly people, who prefer games regarding garden and animals, fish were chosen as the theme of the game.

8) Encourage social interaction: FishCatcher encourages social interaction, since it is also suitable for several people playing at the same time. One possibility is the first multi-player mode where two people try together to catch as many yellow fish as possible. Each of the persons can play with either one or two hands. They can play both standing, both sitting or even one standing and one sitting. The alternative is to play the second multi-player mode, where one player tries to catch as many yellow fish as possible, while the other player catches the red ones. Also for this mode the players can choose to use one or two hands and to sit down or stand up individually. It is even possible to have three or four users playing at the same time if each of them uses just one hand, but thereby may arise the difficulty to place all the people in front of the sensor.

IV. DISCUSSION

This section discusses the implementation and application of the guidelines on the game FishCatcher as well as provides feedback and experiences gathered playing the game. At the beginning, it should be mentioned that by simply considering eight guidelines, the developed game is not necessarily accepted by the end-user automatically since all guidelines offer freedom of interpretation. Furthermore, these guidelines summarize general requirements when developing games for elderly, but do not take personal requirements and constraints into consideration. Hence, it is necessary to consider these additional constraints when developing games. However, the guidelines presented in this paper are the most important guidelines to be considered in any case to address basic requirements. Figure 2 shows an elderly playing the game and providing feedback. In order to use a suitable topic for

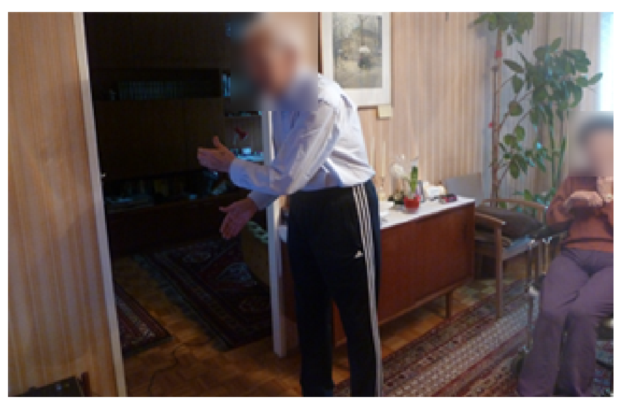

Fig. 2. One person is playing the game during preliminary testing of FishCatcher

the developed game, fish were chosen as topic since they are well known. To avoid difficult and complex gestures, fish are caught by touching them. However, this does not reflect the usual way of catching fish (i.e., by fishing) and thus might be confusing for the elderly. A preliminary test has shown, that only touching the fish to catch them might be even too simple since one elderly tried to wipe over the fish in order to catch it. Hence, simplicity is important but a trade-off for the mapping to real-life applications needs to be found.

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Negative feedback is avoided by the fact that the total score can not be negative. However, touching red fish does result in the loss of points in order to increase the level of difficulty. Since this is needed in order to ensure a minimum level of difficulty and avoid elderly getting bored, this might also have an negative consequence since it can be seen as form of penalty, which should be avoided.

Preliminary test results also indicated that the waving gesture at the beginning to initialize the hand tracker is too complex and might overstrain elderly. This is especially the case if the tracker looses the track of the hand and re-initialization is needed during the game. To re-initialize the hand-tracking the waving gesture needs to be perforemed. If this initialization is needed during the game, no information on how to initalize the game is displayed. This will be improved in the next version of FishCatcher. Moreover, the possibility of using either one or both hands changes the level of difficulty, since it is more challenging not only to catch the yellow fish but also to avoid touching the red fish when playing with two hands simultaneously. Playing the game with two hands enhances the hand-eye coordination, since not only one hand but two hands need to be coordinated at the same time. However, depending on the personal constraints when playing the game, this can either act in a motivating or overstraining manner.

V. Conclusion and Future Work

Playing exergames allows elderly to remain active and socially integrated. This paper presented important guidelines to be considered when developing exergames fitting the specific requirements of elderly people and thus enable them to stay physically and socially active. Following these guidelines does not necessarily ensure that elderly are accepting the game, but ensures to satisfy their basic needs. The game FishCatcher following these guidelines was developed and the application of the guidelines to this game was discussed. Future work deals with an evaluation of FishCatcher and gathers feedback from the end-users in order to verify the feasability of the proposed guidelines.

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Persuasion Mobility in Ambient Intelligence

Lukas Ruge
Institute of Telematics
Graduate School for Computing in Medicine and
Life Sciences, University of Lübeck
University Of Lübeck
Ratzeburger Allee 160
23562 Germany
ruge@itm.uni-luebeck.de

Andreas Schrader
Institute of Telematics
Ambient Computing Working Group
University Of Lübeck
Ratzeburger Allee 160
23562 Germany
schrader@itm.uni-luebeck.de

***Abstract*—Persuasion can be archived with much greater impact using ambient intelligence. Ambient systems may be used to positively influence users' behavior, especially with regard to healthcare. Unfortunately, current state-of-the-art persuasive ambient systems use either mobile devices or are statically bound to dedicated infrastructure. In this paper, we introduce the concept of persuasion mobility. This supports continuous persuasion even when users move between different environments. Besides a discussion of the potential benefits of this approach, we analyze current and developing technological building blocks towards a persuasion mobility architecture.**

Keywords*—*ambient intelligence; persuasion; mobility.

I. INTRODUCTION

Persuasive technology, a term coined in 2003 by B.J. Fogg [1], has been described as "software or information systems designed to reinforce, change or shape attitudes or behaviors or both without using coercion or deception" [2]. Since its inception, a great deal of progress has been made in understanding and developing persuasive technology aided by new technological developments.

With programmable mobile phones, persuasive applications have been created that promise to interact with users whenever and wherever they are. This technology offered to increase the persuasive effect by the promise of persuading in the right moment at the right place, often called *kairos* (named for *Kairos*, the Greek god of "the favorable moment") [1]. Now, with an ever increasing number of sensors on the phone as well as the almost uninterrupted connectivity to the Internet, smart phones provide us with even more ways to achieve persuasion, not just based on place and time, but even on sensed context.

Proposed by Mark Weiser [3], the vision of Ubiquitous Computing is fast becoming a reality. The vision of Ambient Intelligence extends on the idea of ubiquitous computing, proposing a more user centered approach to generate applications in these intelligent spaces to suit the user's needs [4].

With the advent of Ambient Intelligence, technology may again become more persuasive as it adapts to the new paradigm to include not just the resources of mobile personal computing devices but dynamically include the environment as an active component too. Aarts et al. [4] have defined *ambient persuasion* as the use of context-aware, networked devices that enable context-sensitive system behavior to deliver persuasive content.

In this paper, we analyze the key advantages of persuasion strategies combining the power of (personal) mobile devices and (public) ambient devices. Proposing to combine the power of these paradigms, we expand the concept of ambient persuasion by adding the idea of persuasion mobility. Persuasion mobility is defined by the mobility of the act rather than the mobility of the hardware.

Combining and adapting previously developed technology and standards, we show how such mobility may be achieved in ambient persuasion.

The remainder of this paper is structured as follows: Sections II and III describe the two main types of persuasive systems: The mobile device and the ambient infrastructure solutions, focusing on how the advantages of each computing environment are harvested. Section IV extends the properties of ambient persuasion by defining persuasion mobility. Section V provides an overview of technologies and standards that may be used to enable prototyping of mobility in ambient persuasion. In Section VI we conclude with a discussion of future work and draw conclusions.

II. PERSUASION WITH MOBILE DEVICES

Persuasive solutions using mobile devices have been generated targeting a wide range of different problems. In the area of health, the dangers of sedentary work, smoking, bad sleep habits, environmental hazards or psychological problems are among the problems targeted.

BeWell [5] is an application using sensors and mobile phones to enable users to measure their activity level and compare it with the level of friends.

txt2stop [6] is a smoking cessation support system that provides motivational SMS-messages and information to users intending to stop smoking. Messages are send to users for a month providing information as well as distraction.

UbiFit [7, p. 78] is an application geared to promote an active lifestyle. The system uses the internal sensors to infer data on the user's lifestyle and present them on the screen in a garden metaphor.

SoundOfTheCity [8], an environmental monitoring platform using the phones' microphone to measure the noise exposure for users, employs a notification strategy, prompting users to leave a loud area, when a dose threshold is reached.

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These systems show the persuasive power of mobile technology, consisting of a) the *constant connection* to service providers, either using SMS, the Internet or other wireless technologies; b) access to *sensors* that can gather data to infer high level *contextual data* to assess a users behavior; c) the possibility to use the phone to allow for *private access* to sensible information; and d) the *ability to reach* and thereby prompt or nudge the user at the right time.

However, mobile systems do not yet fulfill the promises of *kairos* entirely. The device itself does not truly offer permanent peripheral awareness as it resides mostly in the users' pocket. Handling the phone is not appropriate in all situations and the device itself is limited in the types of actuation it can provide.

III. PERSUASION IN AMBIENT ENVIRONMENTS

Spaces can be persuasive by their properties themselves based on the architecture and design of a space or building [9]. However, the persuasiveness of a space can be increased using ubiquitous computing technology.

In such environments, computer aided persuasion is achieved by amending the physical objects with capabilities that allow them to act in the service of persuasive systems.

Medical mirror [10] is a mirror that augments the reflection of the user with current health data gathered with sensors in the home environment, allowing the user to self monitor his or her health.

APStairs [11] is a project in which the authors have rigged a flight of stairs with sensors to detect the Bluetooth signature of those climbing up as well as an ambient display encouraging users to rather take the stairs then the elevator.

Breakaway [12] uses ambient actuators on a desk in offices to alert occupants when they work too long in a seated position. The project uses the actuator as a reflection of the user allowing for an assessment of one's actions at a glance.

Using physical objects at the location of the user provides advantages over the use of mobile devices. Actuators can enrich everyday objects like mirrors, which the user is accustomed to and knows how to utilize, or artifacts placed naturally into the environments to transmit information peripherally, utilizing a broader range of modalities and stimuli then available to the mobile device.

The medical mirrors and *APStairs* system show how contextual data from sensors placed in the environments can increase the persuasive effect. However, these projects work with a specifically designed hardware-platform and software-architecture, having complete control over the sensors and actuators that only exist in one place and only serve this purpose. In ambient intelligence scenarios, such static constructs will no longer be viable.

IV. PERSUASION MOBILITY

Ambient Intelligence contains, at its core, the idea of a smart environment that changes to accommodate users' needs and wishes when a person enters it. Technology enables environments to gather those needs, either by sensing or by retrieving them from the user's personal profiles and resources. Among a persons' needs may be the execution of systems that take persuasive actions in the environment.

Aarts et al. [4] argue that each ambient persuasive system is context-aware through the use of sensors, and is able to deliver persuasive content to the user. Concerning such delivery, Oinas-Kukkonen and Harjumaa [13] remark that successful persuasion is predicated on the information, that the system has deemed relevant, being presented to the attention of the persuadee (the one being persuaded) and being comprehended. Kaptein [14] extends these requirements by proposing *adaptive* persuasive systems as systems selecting appropriate strategies for the individual user based on estimated success, instead of using a pre-set persuasive strategy that is effective on average. These systems have three core requirements a) *Identification* of the persuadee; b) the technological ability to change *representations* of appeals and c) the ability to *measure* the success of the persuasive attempt.

However, when the person is leaving an adaptive, persuasive smart environment, the persuasive actions should leave with the user and their execution should continue in the next environment the user enters. This includes slow migration situations, where some of the current smart objects get out of reach and new ones appear. In such cases, while these sensors and actuators are properties of the space, the persuasion would be mobile.

Such dynamically instantiated mobile persuasion combines the advantages of persuasion using mobile devices (being where the person is) with the advantages of ubiquitous persuasive entities by allowing to combine the power of both personal and environmental sensors and actuators depending on properties like availability, security, privacy or modality. Only through such combination can *kairos* be truly claimed.

In such a scenario, the environment as traditionally defined by the physical space is replaced by the user environment. The *user environment* may be defined as the physical and virtual environment of the user, consisting, at any given time, of sensors that can sense the users actions and the users surroundings, and actuators that are able to evoke change perceivable to the user.

In the following, we will understand *persuasion mobility* as the act of persuasive software that is dynamically executing its appropriate strategies in the user environment utilizing available sensors and actors.

Persuasion mobility increases the potential persuasiveness of Ambient Intelligence by providing consistency of persuasion even if changes in the user environment occur. It allows for persuasive action to be taken independent of the availability of specific technology rather only based on the determination that a persuasive act is required. Combining this feature with the aforementioned properties of adaptability provides a powerful basis for ambient persuasion.

V. TOWARDS MOBILITY IN AMBIENT PERSUASION

We present a set of technologies and protocols from different fields that, in combination, may provide support to develop persuasive systems that leverage the power of persuasion mobility. In our proposed architecture, the control

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of the persuasive actions would lie solely on the personal mobile device, but the actuation is orchestrated in space.

A. Context Abstraction

We have developed *Ambient Dynamix* [15], an ambient intelligence framework for Android-phones that allows to connect dynamically to the ever evolving set of actuators and sensors in the user environment. Ambient Dynamix supports context generation, abstracting from the hardware to high-level contextual data that is provided to applications subscribing to it, independently of the source of data.

Ambient Dynamix approaches the challenge of the wide area of possible actors and sensors by providing a framework for plug-ins that enable communication with these physical or virtual entities. These plug-ins can be written by domain experts and provided during runtime to the users phone.

Using Ambient Dynamix, applications obtain independence of specific sensors by only subscribing to the high level context that may be generated from different sources as the user environment evolves. Similarly, actions in space can be induced via abstract commands executed dynamically on available actuators. With these capabilities, Ambient Dynamix provides the necessary hardware abstraction to allow a persuasive system to execute its persuasive actions independent of specific devices. Instantiating the actions manually for every possible environment would be inconceivable considering the heterogeneity of smart environment technology.

B. Identification

Moving persuasive actions with the user is only possible, if the controlling entity of the smart environment can identify the user. Kaptein [14] identified this as a condition for adaptive persuasive systems, allowing the system to adapt its means and strategies according to the person. In mobile persuasion, identification is a prerequisite to gain an understanding of the user environment. Proposals for such identification have been made, ranging from RFID or Bluetooth-keys to face recognition or fingerprinting [14, p. 103].

We propose that such identification can be inherently achieved by moving the controlling intelligence into the personal mobile device of the user. Since such a mobile device is inherently personal and usually co-located with the user the persuasive systems run on it can personalize their actions for the specific user in the environment.

C. Device Discovery

Using the mobile device as the central control system for ambient persuasive systems with Ambient Dynamix as the context-abstraction layer it becomes necessary for the mobile device to discover available hardware ad-hoc. The mobile device connects to the ambient devices using different (mostly wireless) standards, such as RFC3927 [16], SLP [17], UPnP [18] and others which allow for discovery and the establishment of services.

Smart phones implement a host of wireless services that can be used to communicate to sensors and actors.

D. Device Capabilities

Current standards for device discovery, like the aforementioned UPnP, offer mechanisms for self descriptions, however, the currently used device profiles lack in information concerning stimulus modality and other actuation features relevant to persuasion. UPnP-profiles have been adapted for the use in different smart environments, indicating that the standard can be used in such a way [19]. When proposing to perform an action with an ambient actuator, Ambient Dynamix has to be made aware of the capabilities of the devices it connects to. Only with such knowledge can it choose the right actuator given an abstract action description. Conceptual structure for ambient actuators as well as the logic of binding actuators to an action have been proposed in the literature [20].

E. Unobtrusive Transfer of Device

When the user environment is evolving, it may become necessary to transfer an ongoing action from one actuator to another since the user has moved out of the scope and can no longer perceive the action. Mobile persuasion requires such transfer of device to happen unobtrusively, without the user intervening. Similarly, the sensors used to produce a relevant context may change.

By orchestrating the persuasive environment from the personal mobile device, this central controlling instance can discover new available local sensors and actuators on the go. Potentially, given a description of the action to be taken, the controlling instance could choose an appropriate actuator as soon as it is found, transparent to the application. This may include the transfer between stimulus modalities, switching, for example, from auditive to visual action if more appropriate.

El-Khatib at al. [21] describe such an architecture for service mobility, using background services on a mobile device to discover available Bluetooth-devices and execute actions on them, handing off services to new devices if needed. In multimedia presentation, the Session Initiation Protocol (SIP) [22] can be used to provide support for session mobility, switching between devices mid-session [23].

F. Coordination of Actuation

According to [24] combining several modalities can enhance the understanding of the message. Since comprehension is one of the key factors in persuasion according to [13], such combination would increase the persuasive effect. Multimodal execution has been discussed in [25]. It requires the coordination of distributed actors in space, which is currently neither supported by Ambient Dynamix nor by the actors.

The heterogeneity of environments means that synchronization between actuators cannot be ensured on the device level. Such coordination must then be, as far as this is possible in distributed systems, be supported by the controller on the mobile device.

G. Measurement of Success

Kraft et al. [26] argue that the "structure of digital health interventions should reflect the psychological chronology of the change process". Such can be said for all persuasive

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technology as the interactions of the system with the persuadee must track the progress made towards the set goal.

Potentially, an additional middle-layer on the controlling device could offer support to ambient persuasive systems by allowing them to define trigger-context specification (in which the persuasive system would be alerted to act) and goal-context specifications (which could be used to estimate the success of the action taken after the trigger-event).

VI. CONCLUSION AND FUTURE WORK

The future discussion on mobility in ambient persuasion must also include the social sciences, tasked with the question how, with the regard to the way a medium shapes a message, different circumstances and environments impact the persuasiveness of any action. Additionally, only psychological research can validate the approach of mobile persuasion.

By providing architectural and systematic support for mobility in ambient persuasion at the device and the middle-ware level, we hope to enable prototyping of systems that can dynamically call upon mobile ambient persuasive means. In this work, by analyzing the advantages of persuasive systems using mobile devices and persuasive systems using the environment, we have defined the parameters of such means and propose a set of technologies which may enable them.

In the long term we hope to tackle the more general question of cross-application persuasion support for persuasive systems on mobile devices. With advances in the development in ambient persuasive systems, system-properties and system requirements due to the persuasive intent of the designer will arise. Providing an additional layer of mobile middle-ware purely aimed at the support of those demands, may enhance rapid prototyping and enable designers to focus more on the persuasive strategy and less on specific implementations.

Ideally, persuasive strategies can be handed as mobile services to the persuasion middle-ware that executes them according to the user's needs and available actuators .

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Positionally Exclusive Broadcasting

Tomáš Žižka, Athanasios Podaras
Department of Informatics
Faculty of Economics, Technical University of Liberec
Voroněžská 13, Liberec, Czech Republic
tomas.zizka@tul.cz, athanasios.podaras@tul.cz

***Abstract*— Early information distribution in crisis events constitutes an important life-saving and social security characteristic. Modern information technologies can provide the possibility of developing systems which can timely send warning messages to citizens within a specific area in order to protect them from a crisis event that occurs in a close region. The current paper attempts to design a new system model aimed to be utilized for warning citizens outside a building about criminal activity in the inner part, within a target area, and prevent them from entering inside. Basic parts of the proposed early-warning system are the RADIO-HELP system enriched by an algorithmic message encryption/decryption process. Combination of these methodologies forms the proposed contribution. People inside the building shall receive by the Police Operational Center encrypted message so that no panic situation will occur and no escape effort will be made by criminals; on the other hand citizens outside the building shall receive clear decrypted message. The message type (encrypted or decrypted) is dependent on the geographic definition of the target area.**

Keywords-broadcasting; decryption; emergency; encryption; information; RADIO-HELP.

I. INTRODUCTION

The transmission of relevant information during non-standard - special and unexpected - situations to demanded places has been always considered to be an important task. However, in today's "modern world", where the development of information technology is rapid, multiple advanced technical resources that can assist in the early and timely distribution of critical and important information to desired locations exist. But, as it turned out in the recent past, the transmission of necessary and sometimes vital information in crisis situations (floods in the Czech Republic in 2013, leakage of hazardous sludge from the aluminum processing plant in western Hungary in October 2010, etc.) was not always effective or failed completely [1][2].

At first, it is necessary to define what can be considered as non-standard situation. This term can include emergencies, crises and other situations that may affect the normal status of life of a certain group of people [3].

Emergency can be defined as an event or situation that is in a certain environment caused by natural disasters, accidents, criminal activity, threats to critical infrastructure, disease, threats to internal security and economy [4]. Examples of emergencies are fires, floods, storms, traffic accidents, plane crash and threats against public safety as a result of criminal and terrorist events and so on.

As a consequence, the question is how could we effectively use available technology to ensure that in case of an emergency or crisis situation, important information will be delivered to concerned recipients on time, in an understandable form and moreover only to locations where the concrete message will be useful.

The aim of this paper is to outline possible methods of distributing information in emergency situations that, additionally, require data encryption, so that they are readable only in a certain location/position. Safety support during criminal activity or terrorist attacks is one of the areas where information coding based on the position of the receiver could be extremely useful.

The rest of the paper is structured as follows: The starting point of the proposed solution is a model situation that is described in the Section II-A. Section II-B mentions the basic system requirements. Section III-A gives information about RADIO-HELP system [5][6], which constitutes the basic building block for the design of a system for distributing positionally encrypted information. Section III-B provides basic attributes of the encrypted positional broadcasting. Details about model of the message transmitting procedure are given in Section IV. The paper closes with a summary in Section V.

II. MODEL SITUATION AND BASIC REQUIREMENTS

A. Model Situation

A wanted criminal is spotted at a certain shopping center. The Czech Police coordinates the measures needed to be taken in order to secure safety within the shopping center. Moreover, a critical police task is to warn the citizens, who are approaching the given shopping center and advise them to avoid the area. Therefore, it is necessary to define the message target area with regard to the shopping center, so that only people located outside the defined region will obtain the broadcasted police warning. As the flow of information within the center is coordinated by the police, the possibility of confusing the shoppers inside the center with a transmitted message aimed for another group must be eliminated, because this could cause a panic. It is also important that messages distributed through this information channel will be kept secret from criminals.

A graphical representation of a model situation is shown in Fig. 1. The area where it should be received decrypted message (clear warning message) is marked in green. Area of shopping center and gray colored circle are areas for which the message is encrypted. The location of an armed criminal is marked in Fig. 1 with red color.

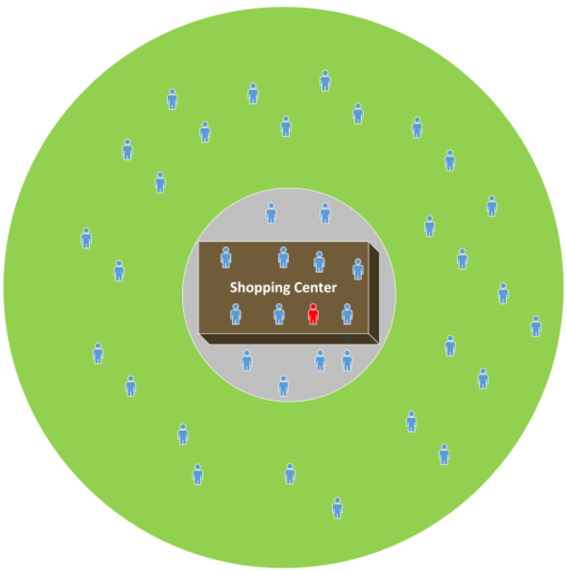

Figure 1. Graphical representation of a model situation

B. System Requirements

The idea of a transmitting encrypted information based on the position, does not aim to develop a completely new system, but to use existing technology components and solutions that will, however, be integrated to new functional units.

The basic requirements are the following:

- Information must be available to everyone (citizens, visitors, etc.) who is inside the target area,
- The ability to encrypt information, based on geographic definition of the target area,
- Independence of the functionality of mobile networks and the Internet,
- The information provider must be a reputable source,
- Security and robustness of the system against abuse,
- The possibility of ongoing testing and verification of functionality.

III. Technical Attributes of the Encrypted Positional Broadcasting

The basis of the proposed system for encrypted positional broadcasting is the use of system called RADIO-HELP [5][6], which is designed and developed at the Department of Informatics of the Technical University of Liberec in Czech Republic.

The aim of the present research team is to create a modern and innovative early warning system that will inform citizens that a crisis event due to criminal activity takes place within a specific area.

More precisely, the currently described methodology will be based on the combination of two tested scientific tools. The first tool is the RADIO – HELP system, an innovative message broadcasting instrument that utilizes both digital and analogue technology.

The second tool that will be utilized as an additive feature to the above mentioned technology, with the ambition to result in the formulation of a modern and innovative application, is the position based encryption/decryption algorithm. The location based encryption algorithmic procedure is also delineated and utilized by multiple researchers who have already developed and tested its functionality on mobile users.

Scott and Denning [7] proposed a data encryption suggested a data encryption algorithm by using the GPS called Geo-Encryption, the functionality of which is based on the traditional encryption system and communication protocol. For the sender the encryption was encrypted according to the PVT (Position, Velocity, Time) of the receiver.

Futhermore, Liao et al. (2008) [8] introduced and proposed the Location – Dependent Data Encryption Algorithm (LDEA). The position based encryption concept is also inspired from a similar approach called Location Based Services (LBS), the importance of which is underlined and thoroughly analyzed by Mohopatra and Suma (2005).

Location Based Services are classified in four categories [9]:

- Emergency service
- Information service
- Tracking service
- Entertainment Service

Taking into consideration the emergency and information service categories and also the target operation of the functionality defined by the present work, it can be realized that a prospective encryption algorithm dependent on the position of the mobile user will be derived from existing similar algorithmic approaches in order to extend the RADIO-HELP functionality and ameliorate the prevention of criminal actions within a target area.

A. Description of RADIO-HELP System

Detailed principle of RADIO-HELP system is described in [10] under the working title RADIO-H (RADIO-HELP). It is based on simultaneous application of analogue broadcasting technology with superposition of digital content (HD RADIO or DRM) or full-digital broadcasts with the possibility of defining the positional coordinates via GPS [5] [6]. HD Radio technology company iBiquity Digital Corporation was selected in 2002 in the U.S. as a key technology for the digitization of radio broadcasting. Currently, this technology carries a large percentage of U.S.

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radio stations. More information about HD Radio Broadcasting is described in [11].

HD Radio technology uses the principle of superposition of the digital signal to analogue signal. The transmitted relation of Radio-Help uses positional codes for identifying areas of compulsory income, i.e., where the broadcast is directed. The receiver in the area is maintained in a standby mode and captured broadcast on fixed rate compares its position according to GPS coordinates with areas included in the broadcast. If there is compliance, it activates forced broadcast reception session. After the broadcasting code ends, the receiver goes into standby mode again. Subscribers of RADIO-HELP that are outside the defined zone will not be disturbed by warning broadcast sessions.

This principle implies that it is possible to transmit separate sessions to more areas simultaneously. Long wave radio transmitters, which with new higher quality broadcasting channels gradually lose their utility, could be used for the broadcast. In such a case, it would suffice to cover the whole Czech Republic just by one central long wave radio sender [12].

Due to the development of IT where circuits for terrestrial broadcasting and positioning GPS are now equipped with most new mobile phones, it should not be technically demanding to use it for purposes of positionally based broadcasting.

B. Basic Attributes of the Encrypted Positional Broadcasting

The concept of the proposed model relies on the early warning broadcasted messages to citizens within and outside a defined area, where criminals and suspects are spotted by the police, and police actions against the latter is about to take place. The core characteristic of the transmitted messages is that they must be based on position. As a consequence, the data sent inside the defined area where criminals are found in the certain moment, will differ from the data content which will refer to the people who are at that time outside this area. In other words, the broadcasted warning message has to be sent as encrypted (i.e., ciphertext) when it is addressed to the citizens inside the target area and as plaintext or decrypted in the case that it is addressed to the people found outside the same area.

It can be, thus, realized that the algorithmic approach which is related to the encryption/decryption procedure of the early warning messages is comprised of the following steps: a) encryption of the broadcasted message and b) decryption of the message when i.e. the mobile user is found outside the region.

Multiple message encryption/decryption algorithmic approaches exist, such as the symmetric, asymmetric, hybrid and GeoEncryption [7]. The contribution described in the present paper, should be based on GeoEncryption algorithm, since it is an approach that takes into consideration the location of receiver, which is core characteristic of the desired system. However, the final algorithmic encryption strategy, which will be added to RADIO-HELP system in order to formulate the target contribution, will be decided in future part of the research.

The aforementioned area can be a shopping center, a park, a hospital, a public organization or even a square. When police receives information about the presence of a criminal in a shopping center the immediate action that should be taken according to our proposed model, in order to protect the lives of citizens and succeed in eliminating the danger to which they could be exposed, is comprised of the below described procedure.

IV. MODEL OF THE MESSAGE TRANSMITTING PROCEDURE

The final critical step of the system's conceptual construction was the flow specification of the broadcasting process of the so called early warning messages. As soon as the criminal's presence (i.e., in Shopping Center) is realized by the Police, there will be an immediate broadcast of a warning message to the citizens who are at that moment inside the area (center) and at the same time for those citizens who are outside the area so that they will not attempt to visit the defined region. In the second case, the message is characterized as the early warning protection message. The model's flow with regard to the early warning message transmission is depicted in Fig. 2. The transmission procedure is initiated by Message encryption. The warning text message is formulated and then encrypted.

In the next step, it is necessary to define the target region of the warning message as well as the area for which the message is encrypted with a special algorithm based on GPS coordinates related to this area.

The third step of the process is the transition of the encrypted message from the Police Operation Center to a special transmitter. If the transmitter does not reject the incoming message due to a technical problem, the same message will be sent at once to citizens' mobiles, radios, car radios and other possible devices in a form of text. For the user group placed inside the target area the broadcasted message, due to encryption, will be displayed as advertising text so that it will not be understood by criminals as warning message from the Police. Moreover, this form of text will help the police take action without the cause of panic to citizens. Panic situation will be avoided since this group of end users will obtain the same encrypted message in the form of advertisement.

However, the message, as it was above stated, will be also addressed to a second group of people outside the defined area. In this case it will be decrypted and displayed in its original form as a clear warning text. As a result the second group will be successfully and timely informed of the forthcoming danger and will avoid the specific area.

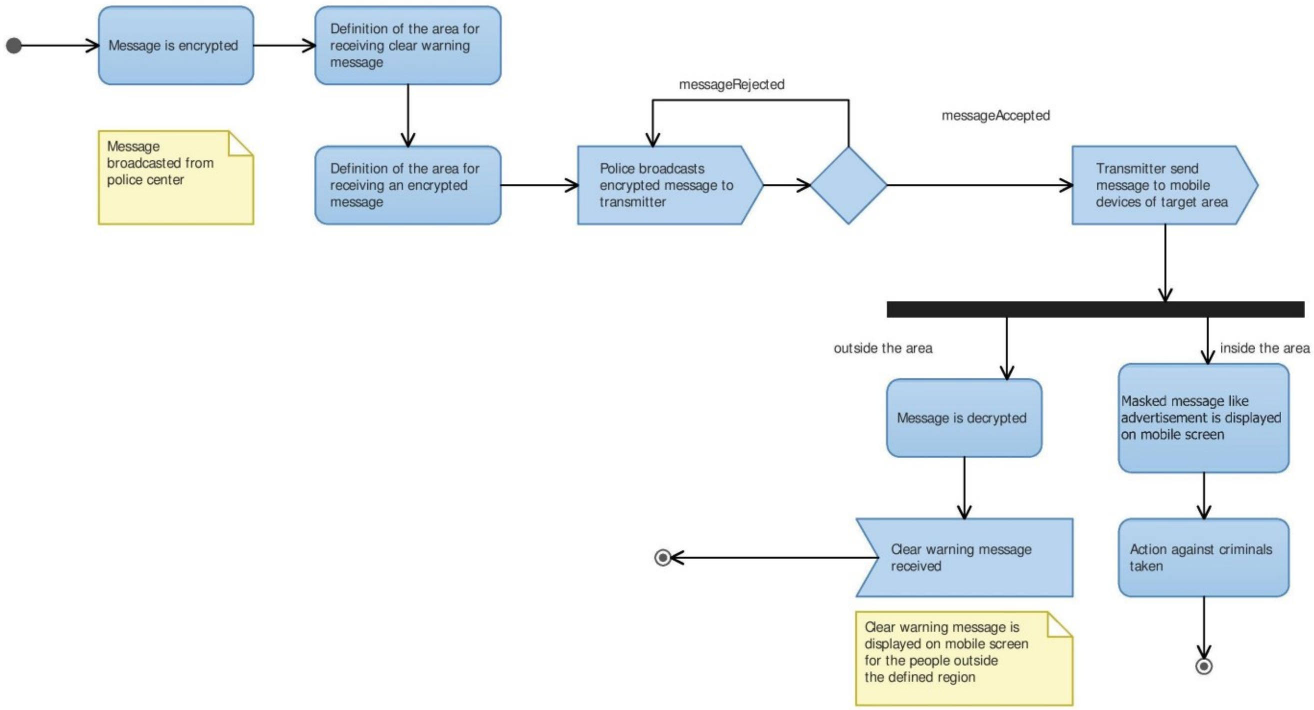

Figure 2. Activity Diagram of the Early Warning Message Transmission Model

V. CONCLUSION AND FUTURE WORK

Positionally encrypted broadcasting system should be a future additional element to the existing concept of RADIO-HELP system, which will ameliorate its functionality. The core idea that authors will further develop is protected by a patent application - PV 2010-260 in Czech Republic (Encryption and decryption of broadcasting based on the position of listener) [13].

Throughout the creation of the model among the core issues that were discussed as possible obstacles of the execution of the process in practice and during real crisis situation, were the following: a) the limit or border between the region inside and outside the target area and its definition, b) the type of the message sent to people inside the area (encrypted) and outside the area (decrypted), since the message will be received by criminals as well and will try to escape, c) algorithmic encryption/decryption methodologies and finally, d) the technology utilized regarding the data transmission (medium of transition – transmitter, receiving devices, etc.).

The above stated topics are considered to be indispensable parts of the new functionality. This way, the combination of RADIO-HELP system and a location based encryption algorithm will formulate an innovative and useful scientific contribution in the area of location based emergency and information services.

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Real-Time Environmental Sensing

Adaptive Surfaces for Architecture

Nancy Diniz
Department of Architecture
Xi'an Jiaotong – Liverpool University
Suzhou, China
nancy.diniz@xjtlu.edu.cn

Hai-Ning Liang
Department of Computer Science and Software Engineering
Xi'an Jiaotong – Liverpool University
Suzhou, China
haining.liang@xjtlu.edu.cn

***Abstract*—In this paper, we present a case for the design and implementation of responsive, dynamic architectural surfaces [2] as potential instruments to provide a structural function together with an aesthetic purpose and informative one. Responsive architectural surfaces are those than provide a dynamic structure—that is, it can change in terms of its appearance and content displayed on it according to different environment factors. These factors include how many people are around a structure and how they behave with and around it. In addition, environment information such air quality, temperature, noise level, sunlight quantity, and humility can all be captured, transformed, and returned in way the is perceivable by people, with the aim of highlighting different aspects of the information. An end goal, for example, may be to use these systems to raise awareness about a sensitive public issue (e.g., air and sound pollution level in an environment) in a subtle, implicit manner. In this paper, we describe three working systems, their purpose and technological features. In addition, we present a system we are currently developing. With these four example systems, we hope to provide a deeper understanding of what responsive, dynamic architectural surfaces can be useful for and their implementation challenges.**

Keywords-Responsive systems; Smart materials; Energy efficiency; Responsive architecture; Ubiquitous systems.

I. Introduction

The main goal of this research is to explore the use of architectural surfaces to communicate in a dynamic way and using different types of environmental information from the surroundings and biometric information from nearby people. We aim to develop affordable artifacts and systems that serve two dual functions: architectural and informational. The first function requires the system to have a permanent, stationary role, while the second function will need the system to have the ability to be dynamic and responsive to the changes in the information it receives. Our focus is on dynamic architectural surfaces, or membranes. A dynamic membrane represents an approach to augment the capabilities of architectural structures by enabling them to sense their environment. In this way, they can capture different types of analog information and, through a transformative process, return the information back for people to see. At the end of this process, we want to reshape how people perceive their environment and to elicit a reactive and affective effect from the observers.

In this paper, we provide a rationale for the need to have these dynamic membranes, describe challenges in their design and implementation, and propose some potential solutions. We will use some systems we have developed in the past and one currently under development to frame our discussions. The paper is organized as follows. In Section II, we examine related work, especially from the artistic and architectural domains. In Section III, we describe three dynamic membrane systems we have worked on. In Section IV, we present our work on a current system being developed. Finally, in Section V, we summarize the paper.

II. Related Work

Architectural surfaces are everywhere and are hence perceive with regularity by people. Often, these surfaces are simply empty, with no useful information displayed on them. Sometimes, they have some limited information on then, but it is often in a static form (e.g., graffiti or a poster). A direct relation can often be observed between human activities and what is manifested on architectural surfaces. These surfaces do not only serve as a means for human expression, they can be important instructions to communicate information to people.

Influential thinkers in the area of cybernetics, the study of regulatory, feedback based systems, their structures, constraints, and possibilities, such as Norbert Wiener [11], John von Neumann [10], and Gordon Pask [9] have considered buildings or their structural components as feedback, reactive systems rather static objects. Architects have also conceptualized buildings as dynamic, evolving structures. For example, John Frazer created a whole new lexicon towards an evolutionary architecture with many experimental projects with his colleagues to investigate

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fundamental form-generating processes and morphable structures [4]. Similarly, Cedric Price (cited in [2]), one of the first architects who actually formulated this dynamic model of buildings, proposed “The Fun Palace”. Although never built, it was one of his most influential projects. The idea central to Price’s practice was the belief that through the correct use of new technology the public could have unprecedented control over their environment, resulting in a building which could be responsive to visitors’ needs and the many activities intended to take place there. The building constitutes an open framework into which modular, pre-fabricated elements can be inserted and removed as required according to need. For Price, time was the fourth spatial dimension, with length, width and height being the other three. Oosterhuis [8] presents the design of a pair of buildings known as the “Salt-Water” and “Fresh-water” pavilions which incorporated numerous electronic sensors into their designs to gather information about both interior and exterior changes. Although the changes were mere virtual projections, the incorporation of computer sensing and display technology in the design of the buildings was a touchstone in the architectural discourse of computationally enhanced environments in which the building is loosely defined as an *Interface*. Goulthourpe’s system “Aegis Hypo-Surface” (cited in [2]) built in 2001 is perhaps the world’s first reactive wall. The piece is a triangle metallic surface that has potential to deform physically in response to electronic stimuli from the environment (movement, sound, light, etc.). Driven by a bed of 896 pneumatic pistons, the effects are generated as real-time calculations. This project has potential for information to literally translate into form, it offers an entirely new medium, digitally dynamic yet materially tactile. Any digital input (microphone, keyboard, movement sensor) can trigger any physical output (a wave or pattern or word). In this Aegis has potential beyond that of a screen to being a fully 'architectural' (i.e., social, physical) interface, where activity (sound, movement, etc.) translates into form (Leach 2002). Another system, “Pixel Skin” [1], is a heterogeneous smart surface that could be used to generate low resolution images, low refresh rate videos or graphical patterns. The interactive wall uses shape memory alloys to actuate each of the 4 triangular panels. The simulation controls the pattern type in response to live weather prediction for the day. This project deals with finding a solution to contemporary architectural surfaces, where conventional windows have to compromise between providing a natural light source and climate protection versus facilitating advertising and information display.

Our research on responsive, dynamic architectural surfaces is inspired by the above work. In the next section, we present three systems we developed. In the section after, we present an ongoing project with an expanding aim and discuss the complexity of implementing it.

III. THREE EXAMPLES OF AUGMENTED, RESPONSIVE ARCHITECTURAL SURFACES

In this section, we present three systems that are based on the idea of dynamic, responsive surfaces. “*Morphosis*”, “*Life Speculatrix*” and “*Nausea Transformer*” [2,3,4,5] are working prototypes that physically respond to local and global external stimuli (movement, light and sound). That is, they “*interact*” spatially and temporally with the environment and its inhabitants. All the three systems have responsive membranes controlled by genetic algorithms which reconfigure their behaviours according to different stimuli and learn how to adapt themselves continually to the evolutionary properties of the environment. The dynamics of the materials in the three prototypes is produced by dozens of actuators made by Shape Memory Alloys (SMAs) and LEDs which react in real time to change the behaviour of the membranes, thereby providing a different visual and sensory feedback to people around them and eliciting different emotional responses from them.

A. Morphosis

One of the first prototypes we developed is Morphosis [6] (see Figure 1), a reconfigurable visual system, which is inspired by the manner in which an organism, or any of its parts, evolve and change form in a short lapse of time, triggered by some combination of external stimuli in the ever changing surrounding environment. It is designed as a model to be suitable for execution of a responsive architecture material and to enable the development of transformable architectural surfaces. Also, by developing Morphosis we wanted to investigate how the learning qualities of a material could be used to improve communication between buildings and its inhabitants. We then continued building upon this experiment to create other variations with the same design concept (see Figure 1). The several prototypes’ behaviours are the result of complex system composed by sensors, microphones, webcams, shape memory alloys actuators, LED’S and a Genetic Algorithm (GA) component.

The main sensory unit is a webcam and a video analyzing program that determines the “empathy” or “repulsion” regarding the current skin behavior by noticing at any given time how close viewers get to the wall. This is actually the Genetic Algorithm fitness function: how bright is the picture captured by the camera. By placing the camera looking down at an angle from the top of the wall, when a viewer comes into the field of view the images gets brighter and the fitness increases. Four input devices inform the computer of the status of the surrounding environment: a webcam, a vibration sensor, a proximity sensor and a light sensor. These sensors are unobtrusively included in the wall and “feel” the environment informing the wall: (1) whether loud music is playing or someone is walking around (vibration sensor); (2) whether there is a rapid change in the ambient light levels (light sensor – web camera); (3) if someone approaches the wall in a touching distance (web camera). These inputs change the behavior of the membranes in shape, trigger sound, motion and light and can create random patterns on the surface, making the surface a responsive part of space, a lighting element, a functional architectural element and a performance piece.

The membranes start its learning process by responding to “empathy” or “repulsion” from the people around it. The environment feeds are inputs for the genetic variations.

These inputs change the sound response behavior of the membrane, change its shape, and trigger motion and light, making the wall a performance piece. The membrane is always aware of its own shape at any given moment because the data is store centrally: the genome and each membrane pixel position. Therefore, when a fitness input is given (via web cam for example), the genetic algorithm knows the current behavior being exhibited by the membrane and thus knows how to correctly classify it.

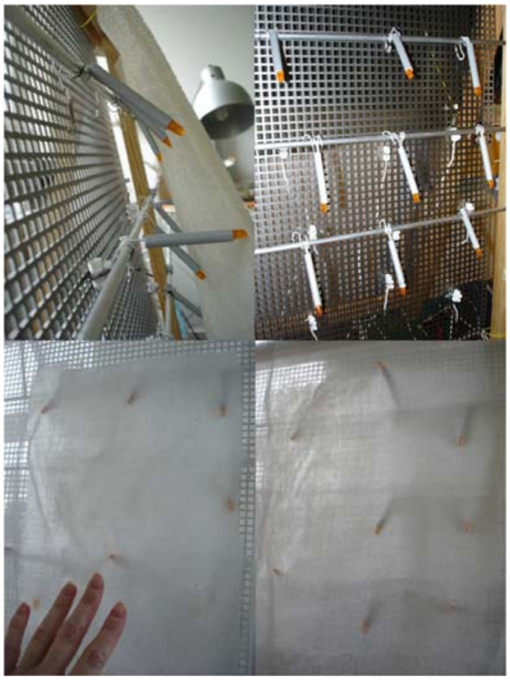

Figure 1. *Morphosis* prototype #1 with its SMA levers above and with membrane below

B. *Life Speculatrix*

Life Speculatrix [6] (see Figure 2) takes inspiration on Grey Walter's "Machina Speculatrix", three wheeled, turtle like, mobile robotic vehicles built between 1948 and 1949. Even with a simple design, Grey demonstrated that his turtles exhibited complex behaviours. He called his turtles "Machina Speculatrix" after their speculative tendency to explore their environment. Life Speculatrix is a kinetic evolutionary physical skin based on digital environmental feedback retrieved through the webspace. RSS/Atom Environmental feeds, like pollution levels, climate features, sound, from around the world will affect its performance as it continually interacts spatially and temporally with the environment and their inhabitants. The fundamental idea is to create an online project as a living, evolving tangible experience.

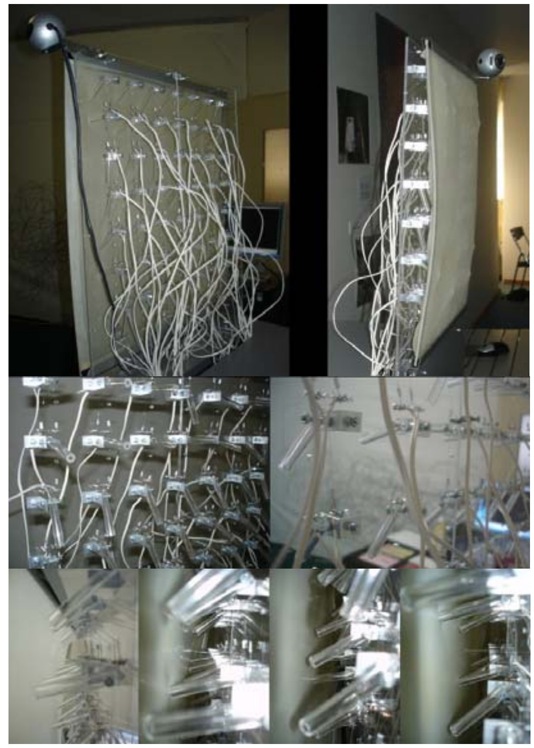

Figure 2. 'Life Speculatrix' prototype

C. *Nausea Transformer*

The word "noise" comes from the Latin word nausea meaning "seasickness", or from a derivative (perhaps Latin noxia) of Latin noceō = "I do harm", referring originally to nuisance noise. For the purpose of this experiment, we consider, all non-musical sounds are to be noise. Noise is a complex concept and source material to deal with; it is an invisible architectural element with an undefined aesthetics. It deeply affects people and yet people feel very powerless to interact with or control it. The fundamental idea of Nausea Transformer (see Figure 3) is to turn noise into a reprocessed living, evolving and tangible experience, by interacting spatially and temporally with the environment and its observers. The purpose is to raise people's awareness to sound, in all its forms: speech, non-speech sound (sound pollution sources) or natural sound, and treat it like data with a corporeal dimension. We aspire to convey an embodiment to an often neglected "hidden dimension", by adding it to a phenomenology and a poetics of visual space. Nausea Transformer [4] is thus a sound reprocessed machine that can unexpectedly create pleasant behaviours by recycling noise into pleasant sound, therefore promoting new interactive experiences to a nearby audience. In other words, it is a reconfigurable acoustic and visual system that records the environmental sound feeds in cycles of a certain time In the next section (i.e., 10 seconds), then, filters that sound and delivers it to the audience with a physical response. The dynamics of the system, materialized as a responsive wall, is made of robotic levers, a latex membrane, sound sources and

LED's which react in real time to change the behaviour of a membrane (Figure 4). The system, creates an evolutionary set of rules for what it considers a "perfect sound environment" and reacts accordingly with a sound source and a physically manifestation. If, for example, the system receives "disturbing" levels of sound, it reacts in "resentment" with a louder cacophony feedback. Simultaneously, it exhibits a physical relation creating "noisy" patterns on the surface through its actuators. If the input harmonizes with the set of rules of the moment, the output can be musical, pleasant and/or humorous. A pleasant sound is defined by low amplitude (not very loud) and by a small difference in frequency between two consecutive samples averaged for a number of samples. The membrane will try to find a behavior that will lower the "noise" (or sound level) made by the viewers by attracting their attention towards it. This is a similar approach to the one previously described for using a webcam.

Figure 3. . "Nausea Transformer" actuators changing the membrane shape according to sound input.

IV. AIRQ WALL: "A WALL THAT TELLS WHAT YOU ARE BREATHING"

A. *Purpose and aims*

The idea behind AirQ is to explore architectural systems that can adapt and transform themselves in response to the constant change of the conditions of our surroundings, in particular air quality (see Figure 4 for a conceptual representation of the system). We want to develop a system which can achieve three goals: (1) to improve the energy performance of existing glass-curtain facades; (2) to increase social engagement on the subject of air quality; and (3) to provide a better ambiance to nearby people by informing them the conditions of the environment (e.g., noise and humidity levels, temperature, etc.) using subtle changes in LED light-based displays. The issue of deteriorating air quality is important in many places (e.g., in developing countries such as China and India), and it is this very pertinent to raise awareness on this issue. In addition, in places where air pollution is serious, production of energy is a key contributor. As such, AirQ will fit suitably to be used in these environments.

AirQ is more challenging to develop than the three systems described earlier. We want AirQ to be a self-sustaining system. That is, it can monitor air quality but with a self-harvest capacity to power itself. The system will be composed of a matrix of units. These units are moveable and detachable components of a glass-curtain wall. They are double sided and have two complementary components on each side: one to harvest solar energy; and the other to display ambient light of different types to provide information about the indoor air quality. In this way, the surface will (1) harvest solar power, (2) control the amount of light coming in, and (3) provide subtle information about air quality levels and other environmental conditions.

A conceptual diagram of AirQ as a dynamic curtain wall which on one side can capture solar energy and on the other side can provide pollution and other environmental information to people by changing its LED colour and pattern display.

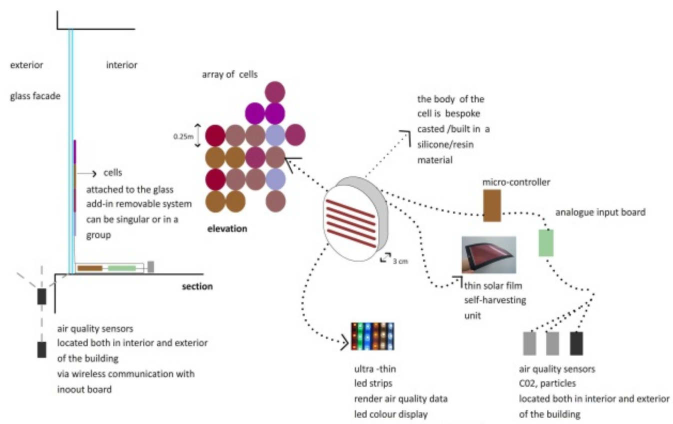

Figure 4. Conceptual diagram of the AirQ wall components.

The system will react locally and remotely to light and air quality data being sent by sensors wirelessly. The solar harvesting unit powers the display surface of the unit. The cells are designed in a matrix where visual patterns will be displayed against "an environmental performance criteria framework" simulated and evaluated according to multiple environmental and social criteria including thermal comfort, day lighting quality, air quality, variable privacy and dynamic visual effects.

The system will reacts locally and remotely to light and air quality data being sent by sensors wirelessly. The solar harvesting unit powers the display surface of the unit. The cells are designed in a modular system. The design

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methodology focuses on the performance requirements through a 1:1 experimental prototyping and evaluation within a glazed surface in a university campus building in China.

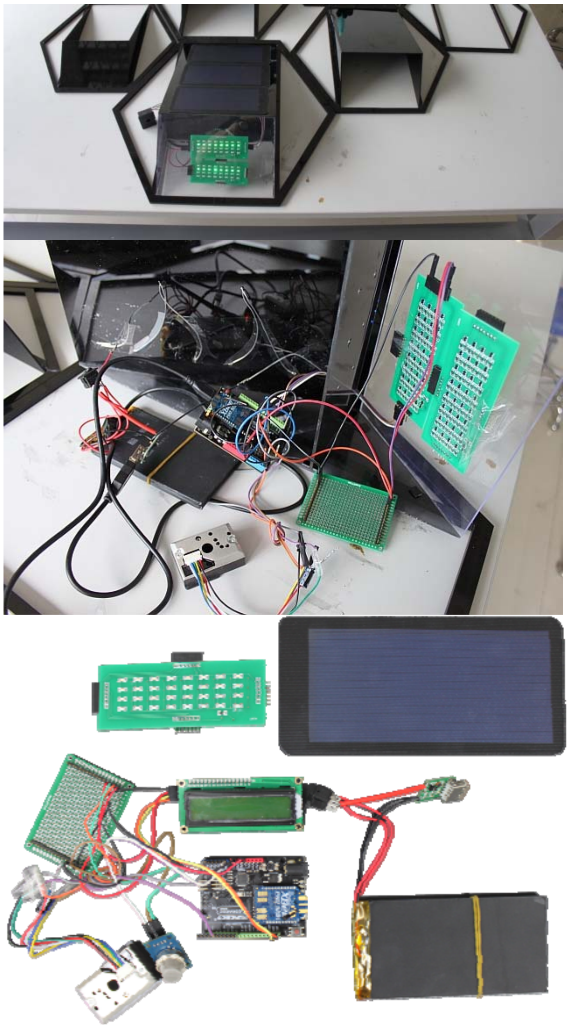

Figure 5. From top to bottom. Prototype as part of a modular assemble. Close up view of the main sensing and display components and bellow the prototype hardware components.

A. Implementation

To implement the system envisaged, there are several technical and hardware issues that need to be considered.

1) Topology of the communication network

Given that we need to capture different environmental data, different sensors will be required. These sensors will have to be connected one receiver. To minimize the amount of physical elements we need to use, we are opting to use wireless components. In this case, the receiver will have to be a transmitter so that it can send the data collected from the sensors. Given that there will be several wireless transmitters (e.g., groups of xBees), we need to have a suitable topology for the network. We have chosen to adopt a Mesh tree network for the system. In this network, there is one coordinator which has to be placed at the right position and distance so that the signals from the transmitters are able to reach it. About six other routers are deployed in the network to relay the signals.

1) Hardware components

Coordinator: The coordinator consists of an xBee module, an adapter for usb-xBee connection, and a cable connected to our server (see Figure 6). Our server is a processing center for collecting and sending management commands for the end user device.

Figure 6. The xBee wireless component serving as the coordinator.

Control Board: The control board is one of the main parts of the system. We have chosen an Arduino-based controller board. It performs the control and coordinating function for the other devices. Slotted on top of the Arduino board we have placed an xBee-shield to connect the other xBee transmitters with the arduino board (see Figure 7).

Figure 7. The control board with an xBee-shield attached.

Figure 8. The traffic of data and the components involved in the process: (left) a sensor; (center) the Arduino board; (right) the LED lights. The arrows indicate the flow of information between the components.

The onboard program reads the data from the sensors and compares the data with onboard parameters. After the comparison, the program decides what LED lights to turn on/off and their value (see Figure 8). The whole hardware set up is shown in Figure 5.

V. Conclusion and Future Work

A small scaled system with its separate connected individual components is working according to our designs and plans. It can capture pollution, noise, humanity, and temperature data at the same time. In addition, the lights are responding to the different parameters set in the program and are able to provide a variety of responsive color patterns and degrees of light intensity.

We are currently looking at the energy aspects of the system. As stated, we want our system to be energy efficient and also to be as green as possible. In terms of energy efficiency, we are looking into components that are simple and with low energy consumption. At the software level, we are attempting to design efficient algorithms and make smart use of its hardware components. For example, although the energy consumption of xBee modules is low, one can further reduce its energy use by leveraging its sleep mode. When used properly, power usage can be further reduced.

In terms of making our system as green and environmentally friendly as possible, we are in the process of attaching small, portable, and efficient modular film solar panels to our working prototype. We aim to find an optimal solution so that the number of solar panels is keep to a minimum; yet, we can obtain a stable and reliable quantity of energy which is enough to power our full fledge system.

As this research attempts to address pertinent issues of energy performance and air quality monitoring, which is very much on the agenda of sustainable problematics of contemporary societies for both developed and developing, we seek answers to the following research questions: (1) Can real time sensing technologies be used effectively for energy efficiency in existing glazing facades? (2) By integrating air quality monitoring and its visual manifestation in buildings, can we provoke new types of social and collective engagement with issues of sustainability? And (3) how can real-time, responsive sensing technology become a source of inspiration, a conceptual framework for designers and engineers to build upon?

The first question is technology-centered, and the last two are more people-centric and require examination of the people's perceptions, feelings, and opinions. To obtain answers for the last two questions, we need to exhibit the system to people and obtain their subjective responses to it. Once a complete, full fledge working system is in place, we will have it on permanent display intermittently during 2 months in total in a series of fine-tuning sessions in a glazed surface in selected private places (e.g., offices) as well as a public area of buildings (e.g., hallways with high traffic) at a University located in a medium size Chinese city. An evaluation period involving observation and questionnaires is applied to collect information about performance and users' response.

In this paper, we have attempted to make an argument for the use of responsive, dynamic surfaces in architectural structures. Architectural surfaces are all around us, but are non-responsive and serve only a structural/functional/decorative purposes. Our goal is to add an additional dynamic dimension to these surfaces by leveraging the power of embedded sensors and computing technologies. By adding this dimension, the usefulness and utility of these surfaces can be expanded. Some uses can be based on improving the aesthetics of the structures. Other uses can be about raising awareness on certain issues. Three working example systems are described in this paper. A further system that is currently under development is also presented to highlight the implementation issues and propose some hardware and software solutions. It is hoped with this paper that researchers from different areas, such as architecture, computer science, and engineering, can work together and study deeper further applications for these dynamic architectural surfaces to make better use of such rich and widely available resources in the form of "augmented architectural functional walls".

We are developing a prototype for an ergonomic box to carry the sensing pack, making the data collection less cumbersome for users.

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