IARIA

# AMBIENT 2017

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

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# AMBIENT 2017

# Forward

The Seventh International Conference on Ambient Computing, Applications, Services and Technologies (AMBIENT 2017), held between November 12 - 16, 2017, in Barcelona, Spain, was devoted to a global view on ambient computing, services, applications, technologies and their integration.

On the way for a full digital society, ambient, sentient and ubiquitous paradigms lead the torch. 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.

The conference had the following tracks:

- Ambient services, technology and platforms
- Ambient devices, applications and systems
- Ambient computing environments, sensors and hardware

We take here the opportunity to warmly thank all the members of the AMBIENT 2017 technical program committee, as well as all the reviewers. The creation of such a high quality conference program would not have been possible without their involvement. We also kindly thank all the authors that dedicated much of their time and effort to contribute to AMBIENT 2017. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

We also gratefully thank the members of the AMBIENT 2017 organizing committee for their help in handling the logistics and for their work that made this professional meeting a success.

We hope that AMBIENT 2017 was a successful international forum for the exchange of ideas and results between academia and industry and to promote further progress in the field of ambient computing, applications, services and technologies. We also hope that Barcelona, Spain, provided a pleasant environment during the conference and everyone saved some time to enjoy the unique charm of the city.

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# Use of Augmented Reality in Sport Performance Visualization: Media Tools for Prosumers

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***Abstract*—This paper describes a proof of concept demonstrator and a prototype system for sport analytics, as well as data visualization designed for sport event spectators to get more insight on the athletes' performance. The demonstrator highlights fully scalable Augmented Reality (AR) based sport analysis data visualization for engaging consumers and sports fans, and gives them a possibility to become more appealing prosumers. The aim is to combine elements of professional sport event visualization with the crowd generated content and social media communications. The AR sport demonstrator consists of two main parts: a) an AR Sport application, and b) AR Sport HTML5 Web service. The AR Sport application is based on the embedded sensor, which is worn by an athlete to collect acceleration data, and Android software that analyzes movement and produces visualizations about the sport performance. The AR Sport service uses the NUBOMEDIA cloud computing multimedia platform with AR capabilities and augments a user generated video stream with athlete specific overlay data. The spectator can use the AR Sport service via a mobile browser and view the augmented video stream on his/her mobile device.**

***Keywords-augmented reality; sport analytics; visualization; multimedia cloud computing***

## I. INTRODUCTION

Augmented Reality (AR) is a technology for overlaying artificial content to the real world view in real time. The mainstream AR applications have often been mobile device applications targeted for personal use, but, recently, AR applications have also been developed for industrial use and for maintenance and building visualization purposes. There exist fewer applications focusing on utilizing AR for real-time sensor information in specific Internet of Things (IoT) environments, such as in sports analytics, where digital devices are hidden in the environment to enable athletes to provide information on their athletic performance.

The rise of the IoT sensors and IoT environments brings a lot of digital information available for ambient environments, but efficient access to this information requires new type of user interfaces. AR will empower bringing the services and information visualizations of invisible digital world to our sight in real time through our mobile devices. AR can assist the use of digital services and the users in decision-making, being capable of representing the services' information directly in physical environments.

We have developed a prototype of service that is easily accessible and scalable for an audience utilizing IoT sensor data analysis and augmented reality visualization. In Section III, we explain how WebRTC based multimedia communication based on the NUBOMEDIA cloud platform with AR technologies were used in the demonstrator. In Section IV, we explain the functionalities of the AR Sports Web service that allows a sport event spectator to receive visualizations for athlete's performance analysis information augmented on the video stream. The innovation of the system is in visual pairing of the athlete's performance analysis and the AR service request, and in the use of the NUBOMEDIA cloud platform, where rendering of the augmented information for the video stream takes place on the server side. The system enables the real time visualization of the data utilizing the AR technologies, as well as a multiuser scenario in which many spectators can easily receive information about an athlete's performance.

## II. STATE OF THE ART

The sports domain has recently started to extensively use sensors both in the amateur and professional level of athletes. There exist numerous solutions for monitoring the personal fitness and sports data from activity and physiological signals. These solutions are mainly used for monitoring and improving individual performance. Advanced sport analytics is using all kinds of data for creating the insights, and analyzing the team and its performance for the benefit of coaching. Visualization of the analytics for a variety of sports is also a well known topic in the research field for team and individual performance [1][2].

Recently, the miniaturizing of the IoT sensors and wireless signal components has also brought the sensors into the equipment, providing very rich data sources for athletic performance analytics. Examples include bats [3], balls [4], and footwear [5].

Personal fitness analysis gadgets [6][7] often display the real time analysis results on the device display or through a smart phone. Additional Web services or mobile device applications are also provided commonly for further analysis and tracking of the athletic performance and achievements

[7]. On the other hand, the IoT sensors that are connected to the sport gear are often used to produce force, position, and acceleration information that is either shown to the person after the action on e.g., a phone's display or reconstructed to the virtual animation of the event [3] [10].

For a long time, broadcasters have augmented visualizations of analytics on the sport feeds to create alluring sports visualizations either of game dynamics or of individual performance. For example, BBC has recently published a web article about these advances [8]. As the sports domain is increasingly interested in innovative and fresh tools for interactive visualization in different contexts and purposes from individual analytics to team performance, the topic has gained wide academic interest [1][2][12][13]. With this technology, we can bring similar informatics to the consumer devices on the sport events and videos. At the same time, the consumer can provide news feed to social media and even to professionals, as they are able to catch the moment with the analytics.

Since there are more data sources available, more attention needs to be paid to real time visualisation of sports data. In addition, developers should study what type of services can be built on top of the emerging technologies. Unifying IoT, AR and sport data analysis will provide a potential to create new services from coaching to engaging the fans of the athletes.

The first AR solutions running on mobile platforms were implemented locally on the client. Until recently, this has been the dominating way to implement mobile AR solutions and one of the well-known bottlenecks in delivery of the AR applications to end users. The WebRTC protocol [11] is changing the playground for multimedia communication systems that have AR capabilities by bringing standardized means of real time video communication to the Web applications. WebRTC allows use of AR services without a need for the installation of special AR-specific software components on a client device. Only access to Internet and HTML5 browser is enough. This tackles one obstacle for AR to become mainstream, as the population of supported devices is extremely large. In addition, this means Web-based development of AR applications is nowadays cost-efficient and it is easy to find expertise. There are also other approaches for Web based AR solutions, for example [14] and [15], but they are using a modified browser to achieve good computational performance for AR tracking.

In addition, requirements for computational power in AR have increased and so it has been natural to distribute the architecture. The advances in development of cloud services and infrastructures have offered solutions for distributed mobile platforms. Many commercial players already use distributed architectures e.g., Vuforia, but this is also an active research topic [16][17], too.

## III. Sport Data Visualisation Cloud Architecture

### A. *NUBOMEDIA PaaS*

NUBOMEDIA is a cloud and PaaS platform supporting development of real-time multimedia applications and a deployment of cloud based multimedia services utilizing WebRTC video communication. The platform provides interfaces that assist development of complex multimedia applications for multiple platforms including HTML5/Javascript, native Android and iOS mobile platforms.

NUBOMEDIA provides interfaces and core functionality for media streaming, processing, PaaS-management, virtualization and load balancing, and an application server for managing users' requests and controls. The platform's interfaces provide a modular structure for the core design and implementation, and tools for developers for using the platform's functionalities in their applications. This paper focuses on the application development capabilities of the platform, especially tailored to support AR visualization of the sport sensor data. The PaaS control functionality and resource management is described in more details in [18].

### B. *NUBOMEDIA Media Plane*

The target of the NUBOMEDIA media plane is to provide comprehensive media streaming and processing capabilities that assist application developers to deploy real-time multimedia communication supporting one-to-one, one-to-many and many-to-many communication models, and processing of the video streams including transcoding, visual content analysis, augmented reality, adding overlay graphics and many other capabilities. The media capabilities are provided by the Kurento media server [19] component of the NUBOMEDIA platform. Kurento is an open source WebRTC media server targeted mainly to provide a Multi-Conference Unit (MCU) for WebRTC based end-user clients. Kurento also supports Selective Forwarding Unit (SFU) operations, but, in this case, many extended capabilities, such as media processing operations, cannot be efficiently utilized. In addition Kurento offers stream management and stream processing for WebRTC clients allowing clients to create different multiparty communication models that application developers can easily embed into their applications.

A particularly interesting feature of Kurento is its pluggable media processing architecture and the capability to manipulate the content of the served video streams. The audio/video stream inside the server can be routed to media elements capable of manipulating or analyzing the content, and thus, providing server side capabilities to provide rich application dependent modifications to the raw A/V streams. The media elements can be chained together. Thus, it is possible to create complex video manipulation processing chains simply by concatenating primitive processing blocks together. The default installation of Kurento contains a basic set of media elements capable of recording, mixing, augmenting, blending, routing and analyzing video streams, for example detecting faces from video streams. Application developers may extend the

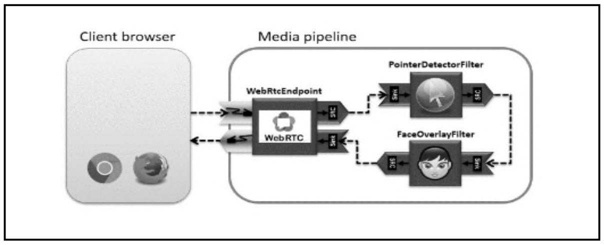


Figure 1. A NUBOMEDIA media pipeline example from Cheambe & al. [18]

media processing capabilities by creating new media elements. The Kurento framework provides a GStreamer based template to assist creation of application specific media elements.

Figure 1 presents a typical set-up for creating a processing and transmission pipeline for a specific multimedia application [18]. WebRTCEndpoints are used to connect the Kurento server to the WebRTC A/V streams that are transmitted between the client and the server. These endpoints can be connected to any media elements for manipulating or analyzing a stream before routing the stream back to the receiving clients. Kurento also offers client libraries for JAVA and Javascript to assist development of Kurento-based applications. It is also possible to control the Kurento server with WebSocket and JSON-RPC in other development environments.

### C. *Sport data visualization extension for NUBOMEDIA PaaS*

The NUBOMEDIA platform provides a comprehensive basis for creation of multimedia communication applications. We extended the NUBOMEDIA capabilities for providing a framework for efficient development of applications that augment image data to video streams and in this way allows visualization of sensor data of athletes for their audience in different kinds of sport competitions. The requirements for such applications include distributed and scalable platform for managing large amounts of audience and athletic related sensor data. The framework supports development of Web based multimedia applications that allow the audience to use their mobile phones' cameras in capturing video streams of athletes and Web browsers in watching of augmented video stream. The augmentation contains measured performance data about the athletes of the sport competition. Depending on the requirements of each specific sport event and properties of the sensor data, the visualization of the performance data may be presented as augmented reality graphics or simple overlay graphics.

## IV. MEDIA TOOLS FOR PROSUMER PROROTYPE APPLICATION

### A. *Use case of the AR Sports prototype*

A long jumper Alan is participating in a local competition. His sport top has an AR marker printed on it and he is wearing an embedded sensor. An Android mobile unit is next to the long jump track and, thus, does not disturb the athlete. Lisa is an enthusiastic fan of long jumping. She is watching the competition and wants to know all the facts. She takes her smart phone out of her pocket and turns on the browser for navigating to the Web page of the AR Sport service. She is pointing the camera at the athlete and the marker on the sport top. The marker is detected by the AR Sport service. Alan makes his jump and, as long as Lisa points the camera at the marker, the analysis of the jump performance is augmented on the video feed and is visible on the screen. Lisa shares the video clip immediately via the social media to celebrate the successful performance of her idol. In addition, Lisa can easily get more detailed information of the different performances, which encourages engaging in sports experience as a fan.

### B. *Proof of concept instance*

The high level architecture of Sport Analysis performance visualization prosumer tool is depicted in Figure 2. The usage of the system is based on two main parts: 1) IoT sport data analysis and visualisation of athletic performances and 2) Use of AR Sports services.

*IoT sport data analysis and visualisation of athletic performances* is depicted in the upper half of Figure 2. This process collects acceleration data from the sensors, analyses the acceleration data, and creates a visualisation canvas for the athletic performance.

*Use of AR Sports services* is depicted in the bottom half of Figure 2. The sport spectator launches a mobile browser on his/her mobile device and navigates to the Web page of the AR sport service in the browser. The Web page opens a camera view and transmits the video feed to the NUBOMEDIA server. The spectator can watch the augmented video stream on his/her device or NUBOMEDIA supports distributing the video stream to a larger audience.

The system presented in Figure 2 contains the following components:

*Athletes* – An athlete will have an AR marker (e.g. a marker that is attached to his/her t-shirt), 3D accelerometer sensors, a mobile device (an Android device) within the Bluetooth range, and the IoT sport data analysis and visualisation application installed to the device that acts as a mobile computation node.

*Sport spectators* – A sport spectator uses the AR Sport service on a mobile device with a browser (e.g., in a Firefox browser) supporting WebRTC and Web connection to the NUBOMEDIA service through the Web page of the AR sport service. The following paragraphs describe the core parts of the architecture in more detail.

*AR Sport application* is an Android application that scans available BLE (Bluetooth low energy) devices, which are in our case VTT Tiny Node sensors [21] (in Figure 3) that are used for measuring the athlete's performance. The Tiny Node consists of integrated sensors including 3D accelerometer, pressure, temperature, and humidity sensors. The AR Sport Application allows selecting a desired Tiny Node sensor and for the selected Tiny Node sensor,

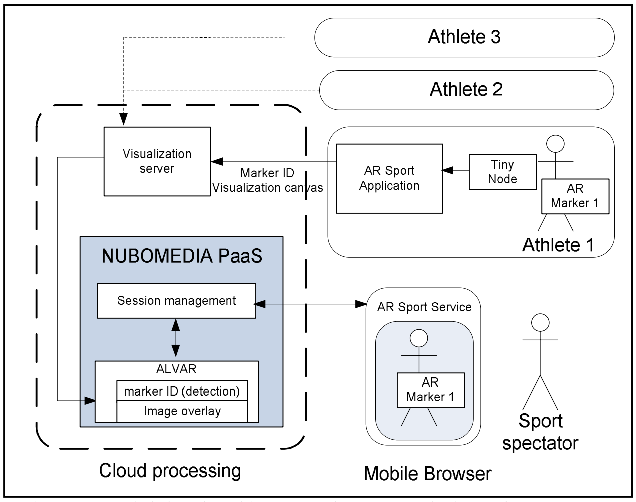


Figure 2. High level architecture of Sport Analysis performance visualization prosumer tool

the application opens a Bluetooth connection. For IoT sport data analysis, the application will first send a message to the Tiny Node for activating collection of acceleration data in the sensor that, in turn, delivers the collected sensor data via Bluetooth for the AR Sport application. The AR Sport application contains analysis and visualisation components. In the prototype, the analysis component uses the acceleration meter data achieved form the Tiny Node sensor. The analysis is performed as follows: recognition of jumps and direction of the jumps by using sliding averages for the x- and y-acceleration data. The jump power is estimated by using maximum vertical acceleration in percentages compared to the best jump of the athlete in the current use session. These values are visualized as depicted on the left in Figure 4. The visualisation shows the direction of the jump (arrow for the jump), name for the athlete, running number for the jump, and power of the jump in percentages compared to the best jump in the use session.

*Visualization server* receives the produced 2D image visualization canvas by using the HTTP post method. The visualization server handles the connection of AR marker ID and the image that are further passed to the NUBOMEDIA PaaS.

*NUBOMEDIA Paas* is responsible for real time video service utilising AR capabilities of the VTT *ALVAR* library [20] that supports marker, planar and 3D tracking based tracking, accurate pose estimation, two types of square matrix markers, and recovering from occlusion. An example of an ALVAR marker is depicted on the left in Figure 3. The NUBOMEDIA service detects the AR marker from a video stream coming from sport spectator's device, and pairs the information of corresponding AR marker with the visualisation of the athlete's performance and augments the image on the video stream. An example of the visualization of acceleration data, video stream from AR Sport Service and augmentation is depicted in Figure 4.

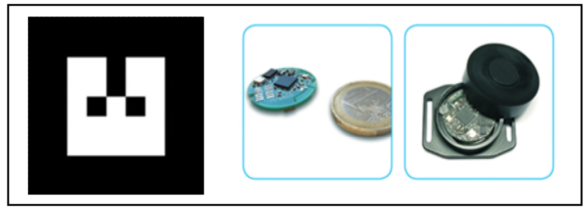

Figure 3. Example of ALVAR AR marker on the left and VTT Tiny Node sensor on the right.

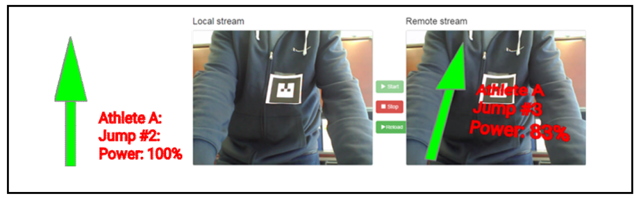


Figure 4. Visualization example of AR Sport Application

The sport spectator can access the analysed performance results through the Web page of the *AR Sport service*. When (s)he access the Web page, the camera of the mobile phone is turned on and the video is streamed to the NUBOMEDIA server by using the HTML5 camera interface input and WebRTC streaming. The Web page is created by an application server that also initializes the AR processing chain in the Kurento media server. The NUBOMEDIA service analyses the video stream and when an AR marker is identified, the NUBOMEDIA service renders a corresponding visualisation canvas of the athletic performance over the video stream and sends the stream back to the browser.

The current prototype implementation assumes that there is only one athlete with a marker and performance visualization that is overlaid on the AR marker. In the future, the system should be extended to use multiple AR markers on separate athletes as the system is capable of visual tagging and pairing of multiple athletes. As each AR marker can be uniquely identified and mapped to the ID of the Tiny Node sensor of an athlete, the corresponding data can be overlaid on the each individual AR marker or an another AR tracking target. In the current implementation, the augmentation is placed on the top of the marker and can be seen only when the marker is visible in the video stream. As the athlete moves, this could become a problem when the marker is out line of sight, but this could be avoided by developing more sophisticated service and user interface. For example, the marker can be used as a trigger for starting the augmentation of the athlete's performance information. In addition, another problem could arise from multiple markers on the camera view as multiple visualizations in the video stream would not be reasonable on a small screen. In this case, the spectator could be given control for choosing the athlete on the display the athlete whose information will be augmented and the system would visualize one performance at the time.

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## V. CONCLUSIONS

This paper describes the AR Sport demonstrator system that utilizes NUBOMEDIA PaaS for multimedia application development. The AR Sport service identifies the athlete and his/her sensor based on an AR marker and connects the visual tag with the visualization canvas created by the IoT sport data analysis software on an Android device. The sport event spectator is able to see the analysis results on the top of the athlete in an augmented reality video stream in real time. The demonstrator showcased that we can create cloud based AR services for sport events for creating totally new type of engaging experiences for the enthusiastic fans. The increasing number of sensors worn by athletes will provide new opportunities to offer visualization applications for the spectators, and it creates a possibility to consumers, such as sports fans, to become more interesting prosumers in sport events. The linking of the information allows tagging of video streams with local sensor data and also with additional information, such as an athlete name, nationality, ranking etc. Future plans include enhancing the user interface based on wider testing and integration of advanced performance analysis on the AR Sport application.

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[accessed October 2017]

# NEMO Converter 3D: Reconstruction of 3D Objects from Photo and Video Footage for Ambient Learning Spaces

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*Abstract*— **In ambient and mobile learning contexts, 3D renderings create higher states of immersion compared to still images or video. To cope with the considerable effort to create 3D objects from images, with the NEMO Converter 3D (NOC3D) this paper presents a technical approach to automatically reconstruct 3D objects from semantically annotated media, such as photos and more importantly video footage, in a background process. By using the Mobile Learning Exploration System (MoLES) with a smartphone, the user creates and collects media in mobile context, which are automatically uploaded into the NEMO-Framework (Network Environment for Multimedia Objects) together with semantic annotations for contextualized access and retrieval. NEMO provides an extendable web-based framework to store media like photos, videos and 3D objects together with semantic annotations. The framework has been developed for Ambient Learning Spaces (ALS) in a research project. With InfoGrid, a mobile augmented reality application connected to NEMO, the user experiences the previously generated 3D object placed and aligned into real world scenes. 3D objects automatically reconstructed from photo and video footage by NOC3D are stored in NEMO and thus provided to all applications accessing the NEMO API. Related to the pedagogical background of our research project, this paper focuses on the technical realization and validation of NOC3D with reference to a realistic scenario for the usage of NOC3D in ambient and mobile contexts. In Section 2, we regard related work. In Section 3, we present a practical scenario for using NOC3D. In Sections 4, we describe the technical environment for NOC3D and our research project. In Section 5, we outline the realization of NOC3D in the ambient context of our scenario. In Section 6, we present our findings and conclude with a summary and outlook in Section 7.**

***Keywords — Mobile media; Mobile learning; Ambient Learning Spaces; Multimedia Storage; 3D Conversion***

## I. INTRODUCTION

Today, in our interconnected society people live in close relationship with their digitally enriched environments. Together with ambient and mobile technology, this individual interconnection between physical and digital worlds plays an important role. Contemporary pedagogical approaches follow the assumption that humans learn individually and during all of their life. Since the learning process also takes place by being and acting in the physical world, one important goal is to offer ubiquitous learning environments; we called them *Ambient Learning Spaces (ALS)*, as described by Winkler et al. [1]. In ALS, working with media in general, and especially mobile media supports the following learning objective: the learner creates contextualized and personalized media, which is stored as digital data and simultaneously enriched with a dynamic set of semantic annotations. This so-called *enriched media* is managed by the *Network Environment for Multimedia Objects (NEMO)* we now use in its latest implementation, based on the original concepts of Lob et al. [2]. NEMO stores text, still images, video, 3D objects, animations, and audio, which are extended by digital properties represented by semantic annotations. Through a digital overlay for physical objects, the NEMO framework provides web-based access to enriched media within ALS. The relatedness of body and space supports the individuality of the learning process. Together with the loss of spatial distance and the exponentially growing quantity of information, this induces new technical requirements, as a single individual is no longer capable of consuming and structuring the globally and permanently available information in its entireness [3]-[5]. ALS enables learners to structure information themselves using ambient technology in web-based applications in mobile contexts on their smartphones. This seems to be fostering the construction of sustainable and mindful knowledge. In this setting, enriched media become the carrier of information utilized in various contexts [6] within ALS, where 3D renderings empower imagination, creativity and learning compared to still images or video [7].

In ALS, enriched media is managed via the *ALS Portal* [6], a web-based platform that features modularized media management, ALS applications, such as mentioned below, and settings stored in NEMO for any ALS applications. For each learning application, a special area within the ALS-Portal allows teachers and learners to manage information, primarily enriched media, depending on their access rights and permissions.

With the help of the *Mobile Learning Exploration System (MoLES)*, a mobile ALS application running on smartphones originally introduced by Winkler et al. [8], students create enriched media in a mobile context to answer given questions for a specific task assigned by their teacher whilst conducting an exploration outside of school. For example, they take photos and video footage from objects they encounter and add digital notes within MoLES by annotating the media. This enriched media is transferred to NEMO for storage. After finishing a field trip, the students use the enriched media they created to reflect and present their findings to their fellow students.

For mobile context in ALS, we have developed the augmented reality application *InfoGrid* that recognizes visual markers or detects Bluetooth beacons both triggering the display of images and video, the playback of audio or the augmented reality presentation and alignment of 3D models provided by NEMO.

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In its semantic repository, the NEMO framework stores media from all the students as outlined. Images or video footage of the same physical objects often occur many times, but differ with regard to the angle, lightning or framing. With the NEMO Converter 3D (NOC3D), this paper presents a solution to make use of such footage collectively created by the students in order to enhance the learner's experience in an ambient learning context.

## II. RELATED WORK

Semantic media comprises the integration of data, information and knowledge. This relates to the Semantic Web [9] and aims at allowing computer systems as well as humans to make sense of data found on the web. This research field is of core interest for our work since it yields structured data in a well-defined, reusable, and contextualized manner.

The field of metadata-driven digital media repositories is related to this work [10] as well. Apart from the goals of, e.g., delivering improved search results with the help of meta information or even a semantic schemata, the NEMO framework distinguishes itself from a mere repository by containing and using repositories as internal components, delivering more complex features through the NEMO logic described below.

NEMO facilitates collecting, consuming and structuring information by interacting device-independently with enriched media, whereas the linked data research targets sharing and connecting data, information and knowledge on the Web [11].

Various implementations exist in order to reconstruct 3D objects from photographic images, but the implementation examined in our work have in common not being integrated into a fully automated web-based framework making use of semantically annotated data in mobile contexts providing background services for ambient learning environments.

In the research field of e-learning, other work connecting semantic structures with learning can be found [12]-[14]. In contrast, our work focuses on linking educational contents with the living environment (Lebenswelt) and thus engaging learners in communicative processes through contextualized and personalized enriched media. For this purpose, NEMO provides means of connecting formal and non-formal learning, e.g., in schools, as well as non-formal and informal learning outside of schools, like in museums. However, NEMO is not used to examine the learner's performance, provide standard learning materials or collect homework, such as Moodle [15].

## III. A PRACTICAL SCENARIO

Michelle, a fourteen year-old student, joins a field trip through the Hanseatic City of Luebeck at school. Prior to the field trip, with the help of the ALS-Portal, Michelle's teacher prepared some questions for the students to be answered using MoLES, for example "*Who are famous composers who left their tracks in Luebeck?*" While exploring their city, Michelle answers this question with the MoLES application running on her smartphone. Michelle uses MoLES and takes photos and tapes videos of what she thinks is related to the question at hand. In this case, for instance, she discovers the statue of composer Johannes Brahms on the riverside of the Trave River. Using MoLES, she takes a few photos and records a video. For every medium she creates, Michelle notes a few keywords and sentences to remember better later on. MoLES uploads this enriched media automatically into NEMO over a secure connection.

Back in school, Michelle prepares a short presentation of her findings from the field trip. Meanwhile, she knows that composer Johannes Brahms never lived in Luebeck himself. Michelle also learns that during the Imperial Era some 'moneybags' from Luebeck were fond of Brahms and centuries later, during the 1990s, the local Music Academy founded the Brahms Institute. She logs on to the ALS-Portal and, among her media, she discovers that the statue of Johannes Brahms is now available as a 3D model, which she incorporates into her presentation. With the help of the mobile application InfoGrid, during the presentation, her classmates, who are surprised that they did not notice the statue themselves before, are now able to take a closer look at it and are astonished to hear from Michelle's presentation, that Brahms is also linked to the Hanseatic City of Luebeck.

## IV. NEMO AT A GLANCE

NEMO is a web-based framework for ALS. As shown in Figure 1, the framework primarily consists of three main levels: (1) the NEMO Application Programming Interface (API) level giving ALS applications access to NEMO, (2) the NEMO Logic level and (3) the NEMO Core level. NEMO as well as NOC3D have been implemented in C# running on Windows Server and Microsoft .NET architecture, also making use of the Windows Communication Foundation (WCF) framework.

The NEMO API (cf. Figure 1) provides access for applications, such as MoLES, interacting through Web Services in an authenticated context over a secure connection. Each application accesses a specific Web Service to achieve a higher level of transparency and

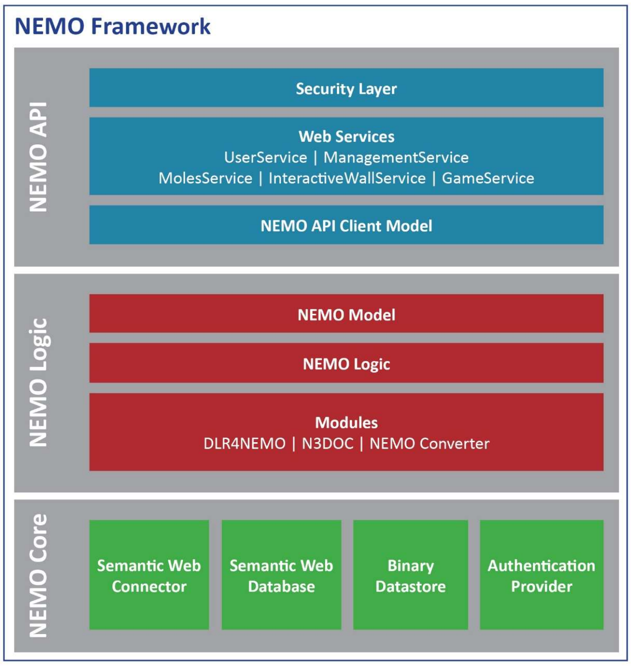


Figure 1: The NEMO framework. The NEMO Logic computes, e.g., coherences, semantic models, and data mapping and a modularised interface for feature extendibility.

maintainability. With the NEMO API Client Model, we created a model for a well-defined data interchange between NEMO and any application in ALS through the Web, following the idea of knowledge representation in a formal and explicit way. From experience, we expect any information entered by a learner to be incomplete, as he or she is still engaged in a process of gathering, structuring, and memorizing, thus NEMO is able to handle incomplete and uncertain information [16] in the NEMO Logic and Core levels. Therefore, the model for any client application is independent of any internal model used by the NEMO framework. In addition, this minimizes the learning curve for ALS application development, as no detailed knowledge of semantic modeling is required when developing an application accessing NEMO. NEMO also provides cross-platform capabilities [17].

In the NEMO Logic, we implemented the NEMO Model, which abstracts ALS as a semantic model. Here, the computational logic resides, which initiates and controls like semantic searches and context analysis in the NEMO Core. In the NEMO Logic, mappings are conducted between the NEMO Model and the NEMO API Client Model through a modified Semantic Object Relational Mapping (SORM). For any Web Service, the NEMO Logic holds the specific application logic and thus interconnecting the applications accessing the NEMO framework semantically through an extendable modular structure with loose coupling. We have already developed extensions for NEMO, e.g., the NEMO Converter (cf. Figure 1), which delivers media in device-specific formats and resolution as requested. For research purposes, another extension tracks all requests, actions, as well the corresponding application state of the NEMO framework. NOC3D also extends NEMO Logic. All data collected is stored anonymously, due to the sensitivity of the data and legal regulations for public organizations like schools and museums. In a defined context of an evaluation, personal information may be collected synonymously. As we develop NEMO with scalability and diversity in mind, NEMO also runs in multiple interconnected instances.

The NEMO framework is based on the NEMO Core where enriched media is stored (cf. Figure 1). A semantic database provides internal storage for any digital entity in the form of semantic annotations. Through the Semantic Web Connector, (cf. Figure 1) any semantic database can be used as internal data store, thus developing applications accessing NEMO requires no knowledge of the respective database query language. Any query result of the internal or any external semantic database is mapped into the NEMO Model. In the NEMO Logic, this data will be processed as described above. Binary media is stored in the Binary Storage (cf. Figure 1), which is linked to the internal semantic database in order to retrieve the stored object as enriched media again and also serves as cache in order to reduce on-the-fly conversion time of the NEMO Converter. An authentication module provides an interface to connect to different authoritative systems in order to check application or media-specific permission settings and user access rights.

## V. The NEMO Converter 3D

NOC3D is developed as a component for the NEMO Logic under the following assumptions, which are partly derived from the scenario described above:

- NOC3D runs in an autonomous mode as a background service without any user interaction required.
- Images and videos are taken with different camera models, mostly with smartphones, from various angles and may contain only sections of the object. Therefore, an input for NOC3D can most certainly not be described as “ideal” or “complete”. The cameras are not calibrated.
- No additional markers are used in the process of media creation, only steady surroundings around the object are required. Every photo or video has to contain surroundings around the object of reconstruction.
- An object for reconstruction has to be sized between 5cm and 5m in height.
- Images and videos may not contain multiple objects and only one object will be reconstructed per run.

### *A. 3D Reconstruction*

In general, the algorithms used in each step and data they require or provide as input and output determine the sequence of steps of 3D reconstruction. For our scenario in an ambient context, we have enhanced their combination and derived parameters from the tests we conducted. At first, from automatically generated and manually entered semantic annotations, GPS coordinates, date and time and with regard to different calendrical seasons, for each possible 3D object, NEMO compiles a selection of images and videos, which possibly show the same object. All media is transferred to NOC3D, as shown in Figure 2. As NOC3D provides a web-based API, NOC3D may be set up on a dedicated server. An identifier passed additionally allows NEMO to link the original media with the 3D object after the asynchronous task of NOC3D finishes.

Operating on the media selection passed on by NEMO, NOC3D at first calculates camera parameters, which will be used for the process of reconstruction later on. 3D object reconstruction starts by calculating match points of all images and grouping them using VisualSFM [18]. This is necessary in order to find the object for 3D reconstruction in the images automatically. Every two images with at least 40 match points are grouped. To receive a high quality result from later steps, all images with a resolution below 1200x1200px are discarded at this point, if a group has a minimum of 10 images with a resolution above 1200x1200px. A group with less than 10 images is discarded, because these will not be of any use for further processing. We found these parameter values through experimental testing during development. Running VisualSFM on the group of images, until no other image of the selection can be grouped repeating all steps outputs a group of images containing the object for 3D reconstruction.

In the next step, depicted in Figure 2, the Center for Machine Perception Multi-view Reconstruction Software (CMPMVS) [19] calculates the cloud of points using the camera parameters from the first step [20][21]. CMPMVS transforms the point cloud into a mesh model and separately calculates a preliminary texture.

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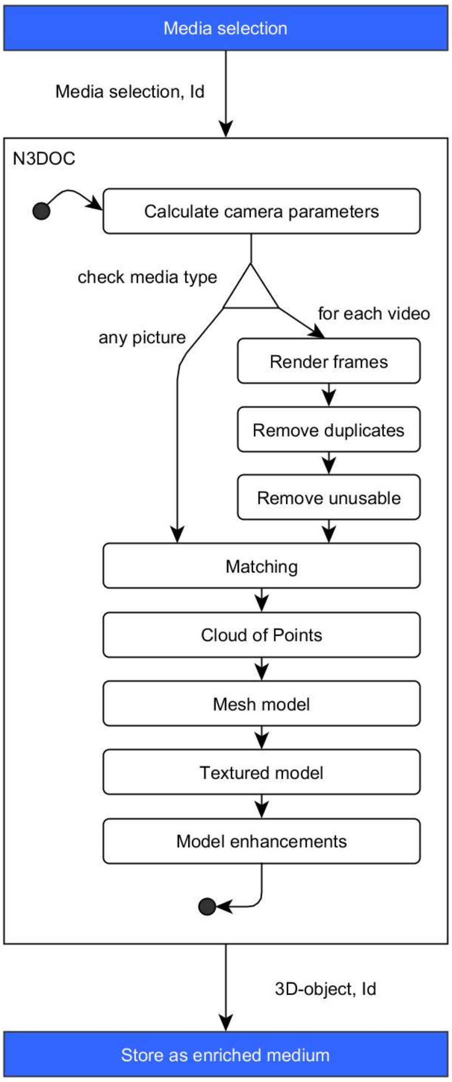


Figure 2. Sequence of the NOC3D algorithm, as more detailed described in section V.A. Media selection as well as storing the 3D object is performed externally from NOC3D by NEMO.

The textured model is handed over to MeshLab [22]. At first, small artifacts are removed and, for web-based and browser compatibility, the number of polygons is reduced to 30.000. In addition, MeshLab is used to close polygon gaps in the reconstructed model, remove devious edges and smooth the entire model. After conversion into a NEMO-compatible file format, NOC3D hands over the completed 3D object to NEMO. NEMO stores the 3D object together with the semantic annotations of the images used to reconstruct the model, omitting those annotations from the enriched media that do not match. Afterwards, the 3D object is available in NEMO.

### B. *3D Reconstruction from Video Footage*

In general, in the process of 3D reconstruction more images from different angles lead to qualitatively better results. During the development of NOC3D through qualitative evaluation with university students, we found out that taking hundreds of images of the same object does not integrate well with our usage scenario. In case of an entire class of 20 or more students, who take at least five images of the same object, NOC3D produces acceptable results. However, the challenge of acquiring sufficient footage remains.

Figure 3. Screenshot of a 3D object reconstructed with NOC3D from 225 images automatically extracted from semantically annotated videos. The blue background is rendered by the 3D object viewer.

The process of acquiring footage used for 3D reconstruction is simplified by supporting videos as input format. As a video generally consists of at least 24 frames per second, just moving around the object taping a video will produce enough material. Before starting the process of reconstruction, videos have to be pre-processed, as illustrated in Figure 2. The video frames are extracted frame-by-frame into images using FFmpeg and stored temporarily. This leads to duplicate or similar images, e.g., when the camera movement around the object is slow. All duplicates are removed during pre-processing using the imaging library ImageMagick, as they do not contribute usable data in the object reconstruction process. In addition, unusable images like from overexposed or black frames will be removed. After pre-processing, all images extracted from the video footage are joined with other images for reconstruction. Our tests indicate, that at least one image (e.g. photo) not taken from a video is required in order to produce acceptable results. This is due to camera parameters, which are not separately stored with each video frame, but are required for the process of 3D reconstruction. As for our scenario, smartphones used to take photos and tape videos available today produce video footage in similar quality to images, which are sufficient for NOC3D, as illustrated in Figure 3.

### C. *Running Time Issues*

With regard to 3D reconstruction, running time of the module is critical. Preparing the media for processing is performed with linear effort, including extracting usable still images from video as shown in Figure 2. All further steps require significantly more effort, depending on the number of images, the objects complexity and the image resolution. Through experiments, we found that this process is speeded-up without losing quality by reducing the image resolution of all images with a resolution above 1200x1200px in half. Additionally, running time improves significantly, whenever images are omitted that do not contain the object, which is reconstructed.

During development, we found that integrating NOC3D directly on the same server with NEMO is unpractical, as 3D reconstruction in general results in high processor (CPU) utilization. Besides, 3D reconstruction performs up to 75% faster on Graphics Processing Units (GPU) than on CPUs. The solution we implemented is to run NOC3D on a dedicated server. Therefore, we extended NOC3D to connect with NEMO through over Web Services. As a

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Figure 4. Statue called "Dorothea" by the people of the Hanseatic City of Luebeck. Number of images used for 3D reconstruction, from left to right: 62, 110, 233, 327.

result, NEMO transfers all footage to NOC3D, which stores all data temporarily on that server. The process of 3D reconstruction is started after all footage has been transferred and NOC3D signals NEMO the completion of a conversion process via callback. Because we are using a dedicated server, we are now able to choose CMPMVS as cloud of points algorithm, which only runs on CUDA-enabled (Compute Unified Device Architecture) GPUs.

## VI. FINDINGS

In summary, NOC3D produces 3D objects (cf. Figure 3) with an acceptable quality given the mobile and ambient context of our scenario in the open standard OBJ-file-format. Due to the automatic process, it is inevitable that 3D objects may contain some surroundings, like, e.g., the grass and path around the statue shown in Figure 3.

In order to integrate NOC3D in a timely manner as outlined in our scenario, most importantly a multi-GPU system consisting of multiple CUDA-compatible graphic boards is recommended. In addition, free RAM capacity of at least the size of the footage used for conversion as well as hard disk storage of at least ten times the size of the footage for temporary storage is advisable. For evaluation purposes, we have tested our implementation with series of photos taken with different smartphones (e.g. Samsung SM-G531F, Nokia Lumia 650 and 930, Motorola Moto G4 and X Play). With regard to the quality of the resulting 3D objects, we also used photos from digital cameras (e.g. Olympus D595Z, Nikon D7000). We have taken footage from 20 different statues across the Hanseatic City of Luebeck, Germany, and compiled them into different selections according to semantic annotations using NEMO. The footage taken cannot be described as 'ideal', as we cared to take mostly snapshots, e.g., only showing parts of the objects or without optimal lightning that would be used when reconstructing 3D models in, for instance, a laboratory with a special 3D scanner. Thus, our tests reflect media expected to be created by students on a field trip, matching our scenario.

Our evaluation shows that, in our scenario, an average minimum of 110 images is required in order to be able to recognize the resulting 3D object as such, as illustrated in Figure 4. The maximum of images is only limited by hardware resources, but keeping in mind the time-consuming process of 3D reconstruction should be limited to a maximum of 450 images. This value is derived from our experiments in context with our scenario and is depending on the objects complexity, desired quality, hardware capabilities, as described below, and the usage

Figure 5. On the left: Statue "Panther" in a botanic garden in the Hanseatic City of Luebeck. On the Right: The output from 175 photos is hardly recognizable as a panther.

scenario. In addition, our tests indicate that using images with the same resolution enhances performance, but our research does not focus on optimizing the algorithms employed for 3D reconstruction within NOC3D. Hence, we recommend setting up NOC3D on a dedicated GPU render server.

Using footage from symmetric objects especially in front of symmetric or repeating backgrounds leads to unusable 3D objects, as the example in Figure 5 shows. Using more photos does not enhance the output. Generally and as expected, higher resolution of footage as well as using more images results in more detailed 3D objects. Nevertheless, using MoLES in context with our scenario limits students to the use of smartphones, which is why or primary focus lies on generating acceptable 3D models from smartphone-generated footage.

During our tests, we found that in some cases NOC3D aborted due to a memory overflow. This occurs due to limited hardware resources, exhausted by huge amounts of input data. Apart from upgrading the hardware, our solution is to catch the exception and remove images with the highest and lowest resolution gradually, restarting the process. With this strategy we try to keep as much information on the object and as much high quality footage as possible. This strategy may be optimized with the help of future experience.

In total, NOC3D generates all sample models without any unexpected result or malfunctioning. Processing the sample models on our dedicated system using an NVidia GeForce GTX 560 takes between four and eight hours each, depending on model complexity and the amount of data to process.

## VII. SUMMARY AND OUTLOOK

NOC3D is a module for NEMO that serves fully automated reconstruction of 3D objects from images and most importantly from video footage created in ambient and mobile context and is used for learning scenarios in Ambient Learning Spaces (ALS). Through NOC3D, enriched media collectively created by students using their smartphones in mobile context is converted into 3D objects. Using Web technology, we integrate 3D models seamlessly with applications from ALS which are used in mobile contexts and in context of learning with media.

It is our hypothesis that learning in a formal and non-formal learning space [6][23], which is digitally enriched through ambient media, fosters cognitive skills and intelligent knowledge in a communicative environment [24][25]. We are going to evaluate this in the near future.

With regard to 3D objects, we plan to evaluate their values in a digitally enriched learning environment. In the setting of our ongoing research, InfoGrid will be deployed in two museums in the Hanseatic City of Luebeck, which are our ALS project partners, later this year and we are currently developing scenarios for integrating 3D objects in museum context. Thus, 3D objects play a vital role in our research project. Later this year, we plan to integrate 3D objects from NOC3D in our ALS Portal in order to provide specific features to allow post processing the automatically generated 3D objects from NOC3D. With the help of these features, the user, e.g., may remove unwanted surroundings around 3D objects.

For any ALS application of the research project, among other features, NEMO provides persistent semantic storage of enriched media. Together with our project partners, two schools and two museums located in the Hanseatic City of Luebeck, the use of these applications together with NEMO in context of mobile and ambient learning is currently being evaluated. NEMO is running in multiple instances on-site. The ALS applications are featuring the creation, presentation, use and interaction with enriched media. The applications are developed for various platforms, in desktop, stationary and mobile contexts. Thus, NEMO is technically connecting the learner’s knowledge into an ambient context, bridging the learning environment and lived-in world (Lebenswelt) to foster sustainable learning and meaningful knowledge.

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# Semantic EnOcean: A Tool for Mapping Syntactic Device Descriptions onto an Ontology for the Internet of Things

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*Abstract*—**This paper contributes to the semantification of the Internet of Things by outlining the efforts in including the Digital Concepts Smart EnOcean Gateway into the ISO/IEC 24752 Universal Remote Console framework (URC). Without our work, integrating the syntactic EnOcean device profiles into semantic environments is bound to an manual mapping of each profile to an appropriate ontology. In this paper, we describe a method and tooling for a semi-automated multistage process to map these profiles to an existing ontology. Strictly speaking, EnOcean device descriptions as given by a commercial EnOcean gateway, namely Digital Concepts Smart EnOcean Gateway, are mapped onto a smarthome ontology, namely DogOnt. As a side effect, the ontology is enhanced to fit the requirements of the device descriptions and extended by the actual devices. Finally, with the resulting ontology as a starting point, URC standard-conform, semantically enriched abstract user interface descriptions are generated. Through semantic enrichment of these User Interface Sockets, the functioning and purpose of the corresponding devices becomes machine-understandable and therefore can be easily used in semantic environments like Smart Homes. Without this additional semantic information, an automated generation of comprehensible user interfaces based on User Interface Sockets would not be feasible.**

***Keywords*–*EnOcean; ISO/IEC 14543-3-10; OpenURC; ISO/IEC 24752; IoT; Domotics; Ontology***

## I. INTRODUCTION

Internet of Things (IoT) emerges rapidly and increasingly covers many technologies that were previously found within the scope of Smart Homes, Ambient Intelligence, etc. The term “Internet of Things” describes the continuous replacement of the classical computer as a stand-alone device by so-called smart objects. Small and embedded computers should no longer be in the focus of attention, but rather support the user with his/her activities [1]. Estimations vary, but there is a broad agreement that there will be many IoT devices: around 20 billion in 2020 [2]. With the growing market, the need for devices that can be easily integrated into the IoT increases.

Devices based on ISO/IEC 14543-3-10 EnOcean Technology [3] are wireless and follow the principle of energy harvesting, which means that the devices are mostly battery-free. The energy required for communication is taken from the environment, e.g., from changes in temperature, solar energy or even kinetic energy of a button press. The EnOcean-Standard is manufacturer-independent and most devices are for domestic environments. The devices can be connected to the Internet through a gateway, for example the recently developed Smart EnOcean Gateway by Digital Concepts [4]. It allows many existing EnOcean devices to connect to the gateway, and the gateway provides a RESTful interface in return.

Every EnOcean device has a profile describing its functionalities in an abstract way. The gateway exposes the profiles based on a syntactic description (JSON REST API) without semantic informations. Hence, the corresponding device and its functionalities are not (easily) machine-understandable, which turns the integration into the IoT to an activity associated with manual work. Purely syntactic descriptions prevent the automated generation of, for instance user interfaces, because necessary characterization of the device, e.g., its type ( lamp, switch, etc.) and other information is missing. An enrichment of the profiles with semantic information would solve this problem.

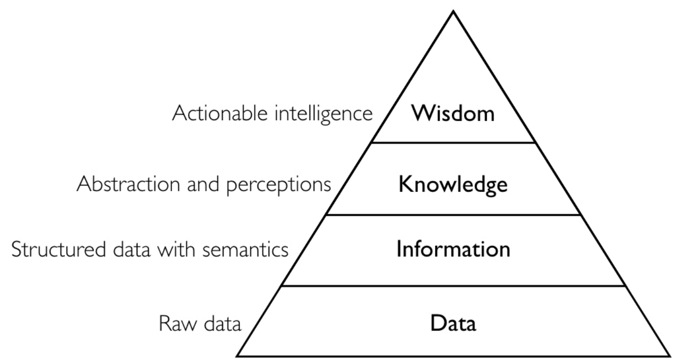


Figure 1. Illustration of the “Knowledge Hierarchy” [5] adapted to the context of the Internet of Things.

The importance of semantics in the IoT in general was pointed out by Barnaghi et al. in their work about semantics for the Internet of Things [6]. They adjusted the well known “Knowledge Hierarchy” [5] to fit into the context of IoT, as depicted in Figure 1. The lowest layer represents the raw data generated by the IoT devices. The next layer is the “Information”-layer. Information can be understood as structured and machine-understandable data with semantic meaning. Based thereon, there is the “Knowledge”-layer, as abstraction and perceptions of the underlying semantic information. On top is the so called “Wisdom”-layer which can be interpreted as actionable intelligence derived from the underlaying abstractions. Clearly, semantic modeling is vital to the development of real knowledge or even wisdom-filled environments.

In this paper, we start in the next section with a brief introduction of the related work, inlcuding the Smart EnOcean Gateway, DogOnt and the URC standard. The sections IIIand IVcontains a description on how to map the EnOcean profiles onto the DogOnt ontology. The generation of the resources for the Universal Control Hub (UCH) – part of the ISO/IEC 24752 Universal Remote Console standard [7] – including User

Interface Sockets, resource sheets, and its semantics will be portrayed in Section V. The work is discussed in Section VIand concluded in Section VII.

## II. Related Work

### A. Mapping of relational data to an ontology

Ontology mapping is not new and in research there is more than one approach to do so. One is the mapping of data from an relational database to an ontology by Sven Peter [8]. His tool is based on the method by Nussbaumer, Haslhofer and Klas [9] specialized for the used ontology. In order to ensure a high degree of precision an semi-automated approach is used. In the approach, the final decision as well as the constraints for the automated part are in the responsibility of a domain expert.

The work shows that a semi-automated approach can be very effective. In our case, the user is the expert for its own smart home and therefor is in control of the final decision.

### B. The Smart EnOcean Gateway

Each EnOcean product comes with a profile that is registered and made public by the EnOcean alliance. A profile is described in the interoperable wireless standard for home and building automation, namely ISO/IEC 14543-3-10 [3]. Recently, there is a commercial gateway available [4] which provides a set – about 150 – of standardized EnOcean profiles. The gateway provides the profiles in a unique but homogeneous way through a JSON API; see Listing 2 for a sample profile of a temperature sensor.

An EnOcean profile starts with a unique identifier, the “EnOcean Equipment Profile” (EEP) followed by a natural language description of the device and a list of function groups. All functions in a group have the same signal direction, either “from” or “to”. The sensor in Listing 2 has a function, which has the direction “from”. “Function”s have “key”s, which are unique in its groups and may have a natural language description analogous to the profile itself. A function has a list of values. A “value” can be a range with “min” and “max” values, “step” and “unit” but also an enumeration of string values. Consequently, the value of a function can be both a numeric value and also a string-based value. For instance, the numeric value is used if the sensor works under normal conditions and the string value in case of exceptions, as depicted in Listing 2 . This fact is a challenge when working with strongly typed programming languages, where variables typically have exactly one particular type, e.g., JAVA.

### C. The DogOnt Ontology

Per definition, an ontology is a “formal specification of a conceptualization” [10]. A special case of an ontology is a Domotic Ontology. “Domotic” stands for DOMus infOrmaTICS, which can be translated to “information technology for homes”. Domotic is often used in conjunction with Smart Homes. A prominent example of a domotic ontology is DogOnt [11]. DogOnt is specialized for domotic environments and was developed by Dario Boninound and Fulvio Corno in 2008 [11]. The aim of this ontology is to transfer domotic environments into intelligent domotic environments by enriching them with semantic information on a manufacturer independent level. Other semantic representations with domotic background is, for example, the ASAP-Ontology [12] but this ontology is too powerful and models many aspects that are not crucial for our use case. Furthermore, we have selected DogOnt because:

```
"key" : "temperature",
"description" : "Temperature (linear)",
  "values" : [ {
    "range" : {
      "min" : 0,
      "max" : 40,
      "step" : 0.157,
      "unit" : "°C"
      }
    }, {
    "value" : "overRange",
    "meaning" : "Temperature sensor
                 failure or out of range"
    } ]
```

Figure 2. The function “temperature” from the EnOcean Profile with EEP A5-20-01 contains a numeric and a string-based value.

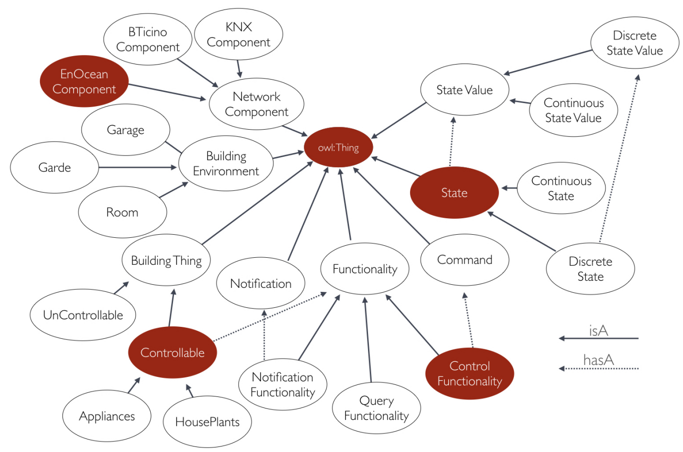


Figure 3. Rough overview over the domotic ontology DogOnt. Important parts are highlighted in red: *Thing*, *EnOcean Component*, *Controllable*, *State* and *Control Functionality*.

1) It is manufacturer agnostic, so are the EnOcean principles.
2) DogOnt is specialized for domotic environments, which most of the EnOcean sensors and actuators belong to.
3) DogOnt is formalized in Web Ontology Language (OWL) [13], a formal description language for ontologies and therefore easily accessible and usable.

A rough overview of a part of the ontology is shown in Figure 3 . Starting from the standard class *owl:thing* of the OWL description language some of the DogOnt classes and relations are depicted. Especially important for our use case are, among others, the classes *EnOceanComponent*, *Controllable*, *ControlFunctionality* and *State*. More specific information about the roles of these classes for our work will be discussed in Section III.

### D. The Universal Remote Console framework

The Universal Remote Console (URC) framework, specified in ISO/IEC 24752 [7], provides an adaptive architecture

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that supports the flexible integration and reuse of heterogeneous software and hardware components, communication protocols, and target appliances. URC allows for interfacing arbitrary appliances and services, so called targets and expose them in arbitrary ways through a mechanism referred to as “Pluggable User Interfaces”.

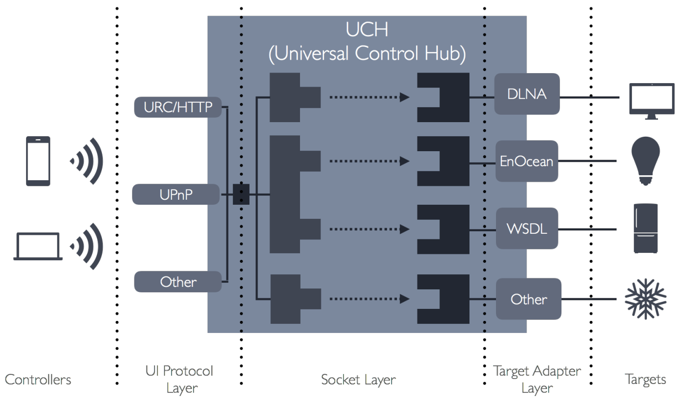


Figure 4. Overview UCH architecture

The advantage of this approach is the possibility to use consistent, secure, personalized and, perhaps most importantly, accessible user interfaces [14]. Users can select a user interface that fits their needs and preferences, using input and output modalities and interaction mechanisms they are familiar with and work well with [15].

The standardized definition of the User Interface Socket (UIS) describes the input and output modalities of a specific target on an abstract level and therefore is the common model of all user interfaces and communication protocols. An UIS contains a flat set of socket elements which are either variables, commands, or user notifications, providing a synchronized communication channel to the controlled device and its current state. The description also specifies how socket elements depend on each other: for example, the commands for confirming or canceling a notification are only relevant while the notification request is active. More advanced dependencies can also be described through the notion of pre- and post-conditions.

The UIS does not provide enough information for generating nice-looking, comprehensible and accessible user interfaces. Concrete instructions on how to build user interfaces are missing: the arrangement and structure of the elements, the language of the labels, additional icons, etc. These can be added as extra resources, the so called “Pluggable User Interfaces”. The socket can then be rendered on some controller, giving the abstract UIS a concrete implementation. The concrete user interface connects to one or multiple sockets in two directions: first, getting and representing the values that reflect the current state of the target, and second, requesting changes in the target’s state through variable changes and command invocations.

The Universal Control Hub – UCH for short – implements the URC standard in a gateway approach. The architecture consists of three important layers: the UIProtocol Layer, the Socket Layer and the Target Adapter Layer, which connetcts arbitrary Controllers with Targets, as shown in Figure 4. In the Target Adapter Layer, each target is represented by a dedicated target adapter that is responsible for the grounding of abstract socket elements with a specific network protocol or other proprietary communication mechanisms. Target adapters usually consist of a combination of software and hardware, which communicates with the corresponding target and translates its signals to URC. Similarly to the EnOcean alliance, the OpenURC alliance [16] develops and publishes sockets that can be usedby any vendor for making their product/service URC ready.

## III. From Syntax to Semantics

Clearly, the sheer amount of EnOcean devices and profiles is a moving target: some device profiles disappear, some emerge. The “EnOcean device profile”, “EnOncean profile” or simply “profile” descriptions are already homogeneous and unified but their structure and content is very close to hardware and without semantic informations. In some cases, even humans are not fully capable to deduce the underlying device by means of a profile. Thus, one big challenge addressed in our work is the enrichment of non-semantic structured data with semantic information in automated fashion as far as possible. Since the semantics are represented in OWL, the challenge refines to a semi-automated mapping of non-semantic structured data to a given ontology. Our solution, a multistage mapping approach is described in Section IV . We use the “HermiT” reasoner [17] for consitency check and ontology queries. As laid out in Section VI, HermiT can unfortunately not be used for identifying subsumption relationships. We query the ontology using the “Manchester OWL Syntax” [18]. Another big challenge to conquer is not to loose any information throughout the whole process. Looking at the children’s game “Chinese whispers”, where some information gets whispered from one child to another, the message steadily alters until it maybe changed completely. This paradigm is also applicable to this work, since at first the EnOcean profiles are mapped to the ontology and at last, semantically enriched User Interface Sockets are generated. Therefore, if some non-important information is evidently lost somewhere in the process, it could lead to larger deviations to the originally profile in the end. Consequently, we needed to find ways to keep all information, no matter how small, in standard- and ontology-conform ways.

Finally, the URC Standard does not specify semantic information for the User Interface Socket, but the URC standards allows for extensions. In connection with the problem above, we had to figure out, how the semantic information can be added in a standard conform manner, which is discussed in Section V.

## IV. Mapping EnOcean onto DogOnt

Semantic information is modelled with the DogOnt ontology, see Section II. We have developed a semi-automated multistage approach to map the profiles to DogOnt by combining terminological, structural as well as semantic mapping techniques on both element- as well as structure-level. The logical process of these mapping steps is shown in Figure 5 . Additionally, we involve human decicions in the loop, in the processing step we refer to as “manual mapping”. This is necessary in order to select “good” ontological candidates, as discussed below.

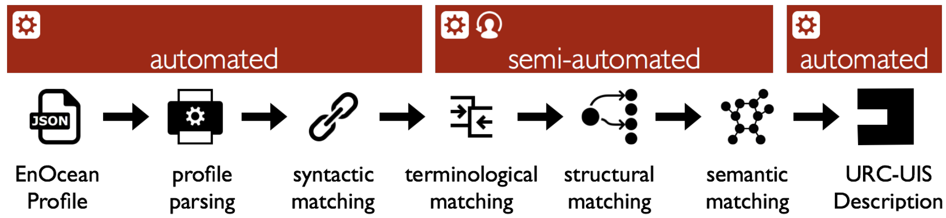


Figure 5. The different steps and matching techniques used to perform the mapping between profiles and user interface sockets.

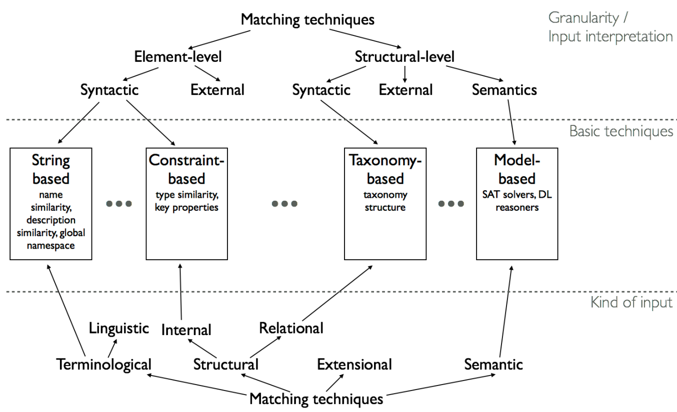


Figure 6. A Classification of ontology matching techniques [19].

Different mapping techniques are used to find best matching partners between concepts in the DogOnt ontology and devices, functions and type restrictions described by the EnOcean device profiles. The classification of these techniques is taken from [19], as shown in Figure 6 . Since DogOnt only comes with a top-level EnOcean concept, each profile gives raise to one new DogOnt entity. Subsequently, for each profile's function and value, new DogOnt entities are created, which are then added to the profile entity.

The first step, see Figure 5 is a fully automated constraint-based mapping technique operating on the profile's complete content, e.g., functions, values, etc. The constraints have been derived on a basis of comprehensive analysis of the profiles, their structures and the available DogOnt concepts. One such constraint states that a new *Controllable* is generated for each profile. Next, the profile's content is translated to ontology concepts. According to their signal direction, EnOcean functions give raise to new sublasses of either *State* or *ControlFunctionality* which are then linked to the *Controllable* with existing DogOnt ObjectProperties using existential restrictions, e.g. *hasFunctionality some...*. Similarily, the profiles' values, namely parameters and return values, are translated to one of four concepts. Values are either a numerical range (possibly with unit and so-called step size) or a fixed string value. A value representing a numerical range corresponds to *ContinuousValue* or a *ParametricCommand* depending on its function's signal direction. Values' properties, e.g., "min", "value", ..., see Figure 2 are translated into DogOnt's "data properties" with appropriate data restrictions and assigned to a new *ContinuousValue* or a new *ParametricCommand*. Fixed string-values translates to *DiscreteValue*s with fixed *realStateValue*s or to *NonParametricCommand*'s value restrictions with fixed value restrictions of the data property *realCommandName*. Recursively, the function specific values are linked to the DogOnt entity representing their corresponding function with an appropriate ObjectProperty, e.g. *hasStateValue* or *hasCommand*. Finally, the *Controllable*'s EEP is assigned to specifically created entities of the *Controllable*.

In the second step, a terminological mapping using the results of the previous step is applied. This mapping applies to the fixed string-values of EnOcean functions, e.g., the value "overRange" in Figure 2 . An appropriate matching partner in *DiscreteValue* or *NonParametricCommand* must have a value restriction of the *realStateValue* or the *realCommandName* respectively, with the exact string value describing the functions fixed value (here: "overRange"). This rule does not apply for *ContinuousValue* or *ParametricCommand*. Here, either the profile's function key is already known or it has to be specified manually. As a fall-back solution, the most general concept is used. If a more specific matching partner is found, the ontology entities created in step one and their object properties are adapted accordingly.

In the third step, possible existing matching partners for the new *State*s and *ControlFunctionalities*s are filtered using relational mapping. Of course, the possible matching partners have to fulfill the type and cardinality restrictions of each *StateValue* and *Command* e.g., a *ContinuousState* has to have one or more *ContinuousValues*. If the *StateValues*s and *Command*s are sufficiently specified in the previous step, the result quickly becomes distinct. In case of an ambiguous outcome, again either the most general matching concept from step one is chosen or the most appropriate candidate is selected by user interaction.

In the fourth and final step, a semantic matching between the already build-up ontological device representation and existing devices in the ontology is performed. Here, possible superclasses with less or equal capabilities are searched for. If the outcome is ambiguous, again either the most general matching concept is chosen or user interaction is required. Since only devices with less or equal capabilities are considered and ontologies allow for multiple inheritance, the user can select multiple devices and corresponding Sub-class axioms for these classes. Eventually, a new ontology entity will be created.

A screenshot from the tool is shown in Figure 7 .

## V. GENERATING OF SEMANTICALLY ENRICHED URC-SOCKETS

We expose the semantically enriched device profiles through the gateway architecture within the ISO/IEC 24752

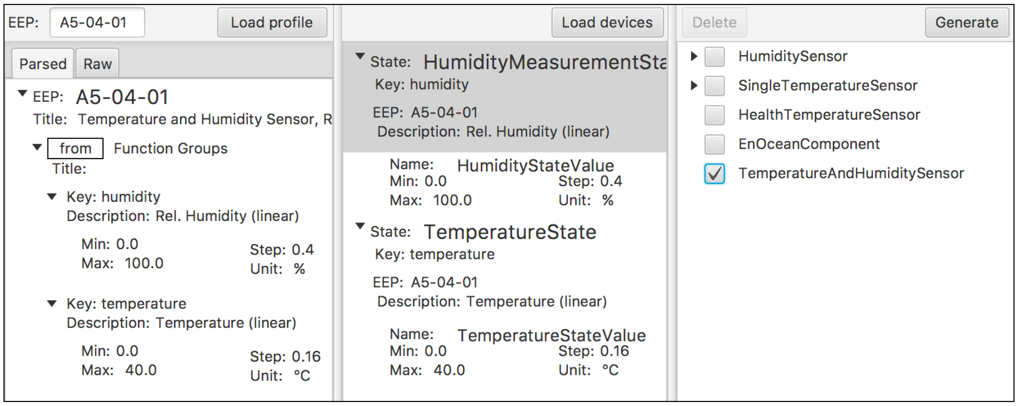


Figure 7. A screenshot of the developed tool. The first column shows the parsed profile, the second shows the current mapping of the functions and values and the third shows the posssible matching partners for the profile in the ontology.

Universal Remote Console standard: The Universal Control Hub (UCH). For every EnOcean profile, a target and User Interface Socket (UIS) description is required. The target description represents the general information of a device, while the UIS description mirrors the exact functionalities. The structure of both descriptions is specified in the URC-Standard [7]. The automated UIS generation is based on entities of the ontology. An entity in the ontology representing a specific profile contains an EEP and other profile specific values and functionalities and will be called profile entity in the following. The semantic enrichment is realised by referencing elements of the UIS and target description with their corresponding entities in the ontology. Thus, the actual version of the ontology is required in order to make use of the semantic information.

As a unique ID for the UIS description the EEP of the corresponding profile is used, since both profile and UIS are an abstract description of the functionalities of a device this is an adequate choice. Furthermore, the EEP is the only unique field of a profile. In the “about”-tag of the UIS description the name of the corresponding profile entity is used.

The generation of the UIS is based on the following rules. “State”s of the profile entity are transformed into variables of the UIS. The type of this variable is a custom type reflecting the corresponding “StateValue”s in the ontology. This custom type is generated as a restricted “xsd:simpleType” and added to the XML schema included in the socket description. These restrictions are either a list of valid strings, the definition of a range or both, in case a function has a numerical and a string based value. To keep all information, the restrictions are also annotated with unit and step size.

Besides the variables, there are commands in the ontology and also in the UIS description. Nevertheless, a direct translation from ontology “Command”s in UIS-commands is not possible, because of the of structure of the EnOcean device profiles, the corresponding behavior of the Smart EnOcean Gateway and the demand to keep all information. The profiles can bundle functions into “functiongroups”. In order to send a command to a device it is necessary to send all commands of one “functiongroup” together. Therefore the generated profile specific “Command”s of the ontology contain information about the “functiongroup” they belong to. In the UIS, one “ControlFunctionality” transforms into one UIS-command and the corresponding DogOnt “Command”s transform into parameters of the UIS-commands. The types of these parameters are handled analogous to the variable types. As type for the UIS-commands “uis:voidCommand” is chosen, because it represents simple commands without timing constrains and return values.

Alongside the UIS description, a “target description” and “resource sheet” are generated. Based on the profile entity, the generated target description uses the EEP followed by the word “Target” as ID, in which the corresponding socket description and the resource sheet are referenced. In order to make the references in the descriptions meaningful, the resource sheet links the corresponding version of the ontology.

## VI. Discussion

The main research topic behind our work was to be able to map all profiles to the ontology. The mapping needs to be error free because of the practical context of the tool. Wrong mapped profiles would lead to unusable User Interface Sockets. Our solution was to include the user in this mapping process, which leads to new research problems on how to model the interaction and how to avoid errors made by the user itself. Therefore finding a way of balancing theoretical research and the practical application was one of the main issues. Besides this interaction there are other discussion points regarding the created tool.

As for now, the ontology extension is kept locally. In the future, they should be made available to third parties via some cloud-based service, such as the OpenURC Resource Server. By doing so, new users do not need to start from scratch but could share already gathered background knowledge. However, semantically “sub-optimal” decision could find their way to the cloud and affect future mappings, which has to be prevented by some validation process, such as the OpenURC Technical Committee Procedures [20].

Another point of discussion is the selection of the DogOnt ontology. DogOnt has the advantage of being specialized for domotic environments, the field of use of this work. Furthermore, it is possible to model the required objects and functionalities with some room for improvement and extensions of the work. However, DogOnt limits our work since some necessary classes are not modelled in a generic manufacturer-independent way. As an example, the class *TemperatureSensor* has a Zigbee-specific *GroupFunctionality*. Moreover, some classes are not specific enough. For example, *Sensor* is a subconcept of *Controllable* but with no additional properties. Therefore, a reasoner will, based on restrictions, not distinguish between the sensor class and its superclass.

During this exercise, we also identified some semantic inconsistencies leading to problems like the "one-to-many" mapping. For example the class *DoubleValuedState* has the restriction minimum of two *StateValues* instead of exactly two. Thus, entities with three *StateValues* would fit the restrictions of being a *TripleValuedState* and also a *DoubleValuedState*.

The solution to overcome these problems is the already mentioned user interaction. Of course this could lead to subjectivity, but regarding the domain of the tool as the smarthome of the user itself, a customized or subjective view on the objects in it and therefore its digital modeling seems justifiable. Another benefit of the user interaction is, that the mapping does not only work for straightforward profiles but also for more specific ones. The learning behavior of our tool also helps to improve the automated process, profile by profile.

## VII. Conclusion

This paper presents a method serving two main goals: firstly, a completely information-preserving mapping of syntactically described EnOcean device profiles provided by a commercial EnOcean Gateway in JSON format onto the DogOnt ontology. Secondly, based thereon, an algorithm for the generation of semantically enriched ISO/IEC 24752 URC standard-conform User Interface Socket descriptions. The method has been fully implemented and the tool processes successfully all ~150 EnOcean profiles provided by the used gateway. The tool opens up a whole range of possible extensions. Perhaps most prominent, given a Smart Home installation based on the Smart EnOcean Gateway and the Universal Control Hub middleware, new EnOcean devices will be automatically integrated into the Smart Home environment.

Overall, this work lifts the integration of EnOcean devices from the data and information layer into the knowledge layer as described in [5]. This makes a future proof usage of the EnOcean world possible within the semantic IoT.

The OpenURC universe benefits from the semantic enrichment of the UIS in many aspects. For instance, the UCH respectively its UIS can be interpreted by Smart Services which is essential for the use of the UCH in the scope of the DiDiER project [21]. Semantically enhanced UIS descriptions significantly increase the quality of automatically generated user interaces. In the near future, we will make the results and resources available by publishing it within the scope of the OpenURC Alliance [20] and the method for the semantification of User Interface Sockets developed in the context of this work will be used in the DiDiER project.

To this end, our method has so far been based on structural mapping techniques rather than on semantic ones and the power of the description language OWL itself. In the future, we plan to improve our method accordingly, we are confident that the inclusion of more elaborate devices will support this vision.

## Acknowledgment

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# Ambient Health Monitoring System for Solitary Elderly

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***Abstract*—In this paper, we propose a sensor-based monitoring system that evaluates the health status of solitary elderly based on daily living activities, and provides signs of declining health to a local nursing center without explicit user interaction. We focus on three daily living activities: urination, kitchen work, and practices for good personal hygiene, because these activities are closely involved in maintaining a healthy lifestyle. These activities are usually accompanied by water use. There are some regularities in the water use during these activities, and the resident's health status is correlated with the regularities. Therefore, the proposed system monitors health status by using water flow sensors which are attached to faucets in the kitchen, washroom and to the toilet. An advantage of this method is that the system can be readily installed in any type of housing at low cost. In addition, this system does not require personal data to be saved or transmitted. The monitoring systems have been installed in three volunteer's housing and some results from this experimental use will be presented.**

***Keywords*–Health monitoring system; Solitary elderly; Water flow sensor; Active RFID tag; Vibration sensor; Quotidian activity.**

## I. INTRODUCTION

We are confronted with an increasing population of solitary elderly, many of whom live in their own homes and for whom dangerous situations that may require medical attention are ubiquitous. However, the number of caregivers available for frequent home visits is limited. Thus, new care services, such as those that use monitoring systems, are needed to cut costs in health care while still providing security and adequate medical treatment for people who live alone.

There are a number of compact wearable sensors used for the detection of emergencies, such as sensors for the observations of vital signs [1]. This kind of emergency sensor has one disadvantage: it has to be worn constantly and operated actively, making it highly limited in regards to functionality and comfort. Recently, research into this aspect of health care has focused on capturing the activities of daily living by using non-contact monitoring systems. Such monitoring systems can be divided into two categories: to identify a situation that the resident requires immediate medical assistance, or a situation that the resident's health conditions deteriorates at slow rate. One typical example of the first case is a broken bone due to a fall and the second case is caused by hidden diseases, such as a diabetes or by malnutrition. In this paper, we focus on deteriorating health at slow rate, in other words, a sensor-based monitoring system that evaluates the health status of an elderly person based on his/her daily living activities and reports his/her health condition to a local nursing center without explicit user interaction.

One method for the early detection of deteriorating health is monitoring systems that use position sensors. The best-known representatives of position sensors are infrared-ray sensors, which are installed in the living room, bedroom, corridors, and so on [2], [3]. Positional information for the person is acquired from the detection of body heat as he/she moves through the house. A model of the normal day-to-day behavior patterns is created based on the individual's at-home habits, such as their movements, living room use frequency and living room use time, which are derived from positional data [4], [5]. Problems with the individual's physical condition can be detected when there is a major variation between the model behavior and actual behavior patterns. The development with this kind of day-to-day behavior models using machine learning methods is that they require a solid database with a substantial number of cases in order to achieve reasonable results. In addition, a unique model must be made for each and every person. Therefore, the installation of such technologies takes a great deal of time.

Moreover, these position sensors provide only indirect information on health status. In other words, positional information does not always correspond to vital activities related to health status. From the viewpoint of reliability, it is desirable to directly specify normal daily activities and then to detect variations which may be signs of a dangerous situation. TV cameras can observe daily activities and detect dangerous situations, but privacy concerns make their introduction into private homes limited. A smart meter, which is used for the billing of electricity, can also be used for activity recognition [6]. Momentary variations in power consumption are recorded in the smart meter, and use of household appliances, such as a vacuum cleaner and a toaster oven, can be ascertained from the variations, allowing the inference of daily living activities. However, it is very difficult to analyze the variations in power consumption.

We focus attention on three quotidian activities: urination, kitchen work, and practices for good personal hygiene, because these activities are closely involved in maintaining a healthy lifestyle. These quotidian activities are usually accompanied by the regular use of tap water, and an individual's health status can be correlated with this regularity. Therefore, we propose a health monitoring system that uses the water flow sensors that are attached to faucets in housing. An advantage of this method is that rule-based methods can be used for analysis and interpretation of the sensor data [7], [8]. The rules can be derived from experiential knowledge of water use during urination, kitchen work, and practices for good personal hygiene. In addition, these sensors are available at a reasonable cost. The system can be installed easily in any type of housing, and no interaction by the user is required. No personal data, such as photographs or video recording are saved in the system or transmitted.

This paper is extended in some ways from our previous paper [9]. The former system was just a prototype to see whether the sensor system can acquire correctly the time and frequency of water use from the quotidian activities. The present system has been redesigned and improved at the points of reliability and energy consumption in order to keep functioning for a long time in real environments. The monitoring system has been installed in three volunteer's housing and some results from this experimental use will be presented. This paper is organized as follows. In Section 2 we give a brief outline of the proposed method and monitoring system. Section 3 describes the technical aspect of the monitoring system. Section 4 describes the implementation of the monitoring system and experimental results. Concluding remarks and future goals are given in Section 5.

## II. Overview of the Proposed Monitoring System

In our system, we focus on three quotidian activities, that is, urination, kitchen work, and practices for good personal hygiene. As mentioned below, there are some regularities in the water use during these activities, and the resident's health status is correlated with the regularities.

We know that humans urinate an average of six to eight times a day; thus, if an individual makes much less or much more frequent use of the toilet, then some illness or problem can be suspected. If one wakes two or more times before dawn to urinate, this can also be a sign of poor health state. Common causes of such symptoms are a urinary tract infection, diabetes, stroke or other neurological diseases, chronic kidney disease, and so on [10], [11]. Therefore, the number of times and the time of day that an individual urinates are important signs of health status. It is possible to infer the health status by checking the flow of water at the toilet's flush tank in the bathroom.

Cooking is also a fundamental human activity. It is not only connected with the joy of eating but also deeply affects various aspects of human life, such as health. Needless to say, healthy eating habits improve quality of life and help the elderly maintain good health. It is said that changes of appetite occur in conjunction with diseases of the digestive system, taste disorder, dementia, and so on [12]. Therefore, daily kitchen work also includes an important sign of health status. At mealtimes people use a large volume of water in the kitchen for cooking and washing dishes. Time periods when the use frequency of tap water in a kitchen is high appear in the distribution graph of water use, and are very likely to be observed in the morning, at around lunchtime, and/or in the evening. Such activities can be inferred based on water flow at the kitchen sink.

If people are healthy, they usually wash their faces and rinse their mouths when they get up in the morning and go to bed at night. They sometimes perform activities, such as hand-washing to keep themselves clean. It is said that poor personal hygiene occurs in conjunction with depression, dementia as a result of Alzheimer's disease, Parkinson's disease, and so on [13]. Such activities as maintain personal hygiene show important signs of health status. Although the volume of water use at a washroom sink is not large and the water use is scattered sparsely in the distribution graph of use frequency, such activities can be inferred based on water use at a washroom sink.

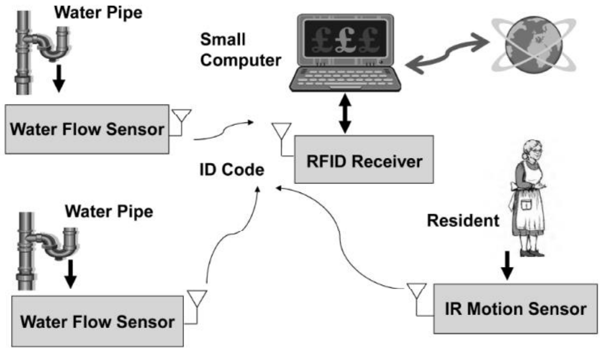


Figure 1. Functional block diagram of the monitoring system.

Therefore, monitoring the duration of tap water use at kitchen and washroom faucets and at toilet at particular times of day, makes these three activities (urination, kitchen work, and hygienic activities ) directly recognizable, and signs of ill health in the elderly can be deduced. Figure 1 provides the functional block diagram of the proposed monitoring system. The monitoring system consists of three main components: water flow sensors with active radio frequency identification (RFID) tags, an infrared (IR) motion sensor with an active RFID tag, and a small computer with an RFID reader. The water flow sensors are attached to a water pipe near faucets on the kitchen and washroom sinks, and to the water pipe to the flush tank of the toilet in the bathroom. These sensors transmit a radio frequency (RF) signal with an ID code, at one-second intervals while water is flowing through the faucet. The IR motion sensor is installed in a place where the resident comes and goes frequently, such as the living room, a bedroom, or corridors. It sends an RF signal with its ID code when the resident passes the sensor. The monitoring system can acquire information about whether the resident remains indoors based on the time stamp of the ID codes from the motion sensors. The computer is placed in the house of the resident and is wirelessly linked with the sensors through the RFID reader. The computer records the receipt time of the ID code sent from each sensor, judges the health status, and sends a report to the nursing center via the Internet.

The reasoning program installed in the computer derives the time and duration of tap water use from the time stamps of the received ID codes from each faucet. In addition, it estimates the at-home time of the resident from the IR motion sensors. This at-home time is used to reinforce reasoning of health status based on data from the water flow sensors. A model for normal water usage is created based on experiential regularity, as mentioned above. When there are major variations between the model and actual usage patterns, it is assumed that there is something wrong with the resident's physical condition, and the reasoning program reports signs of declining health to a local nursing center. Then, a caregiver will visit the resident to verify his/her condition.

## III. Equipment for the Monitoring System

This section describes the technical aspect of the functional blocks shown in Figure 1. We considered the following thing for the system redesign. The sensor system should be reliable and low power consumption for long time operation, because it is not expected that the monitoring system is maintained or managed by the user.

Figure 2 illustrates the latest prototype of the water flow sensor. A water flow sensor consists of a vibration sensor, a sound-activated switch and an active RFID tag. Mechanical vibration in the range of 0.5 to 10 KHz occurs at the water pipe near the faucet while tap water is running. The vibration sensor is designed to be attached to the water pipe near a faucet to pick up the mechanical vibrations. A ready-made vibration microphone used for tuning musical instruments, such as guitars can be applied to the vibration sensor, which is available for less than 5 euros in the market. The microphone is clip-on and the point of a clip is machined to fit the shape of a water pipe. Figure 3 shows an example of the vibration microphone clipped to the water pipe to the flush tank of a toilet. The active RFID tag has a unique ID code (8 characters), which provides information about its location in the house. When the microphone detects mechanical vibrations from the faucet, the sound-activated switch turns on the active RFID tag. Consequently, the tag sends a radio frequency signal (2.4 GHz) with its ID code. The signal is transmitted at one-second intervals while the water continues to flow through the faucet. The monitoring system measures the time of running water from each faucet to obtain the use frequency and duration of tap water use in everyday life. The tags can send signals indoors to a range of up to about 15 m, which is sufficient in a normal house. The sensors have a rechargeable lithium polymer (Li-Po) battery (6600 mAh) built-in and can keep functioning for about 13 months.

Figure 4 shows the prototype of the IR motion sensor. The motion sensor consists of a pyroelectric infrared sensor with a Fresnel lens and an electronic circuit to form the module, and an active RFID tag. The motion sensor is installed at a location in the house where the resident comes and goes frequently. The motion sensor detects motion by checking for a sudden change in the surrounding infrared levels, which is caused by the resident's body heat as he/she passes the sensor. The sensitivity of the sensor is limited to detecting a person up to 4.5 meters away. When the infrared sensor module detects such changes of the infrared levels, the module turns on the active RFID tag for 2 seconds. Consequently, the tag sends an RF signal with its ID code twice (once per second). The monitoring program records the time when an ID code was transmitted in order to estimate how many hours the resident was at home that day. The sensors have a Li-Po battery (6600 mAh) built-in and can keep functioning for about 7 years.

Figure 5 illustrates a small computer (Raspberry Pi B+) with an RFID reader. The RFID reader receives the RF signal from the tags, obtains the ID code and reports it to the computer through a USB port. A reasoning program is installed on this computer, which is written in C and runs on the Pidora (a kind of the Linux for the Raspberry Pi).

The number of times that ID codes were transmitted from the faucets indicates the amount of time that there is running tap water, and this is proportional to the amount of water

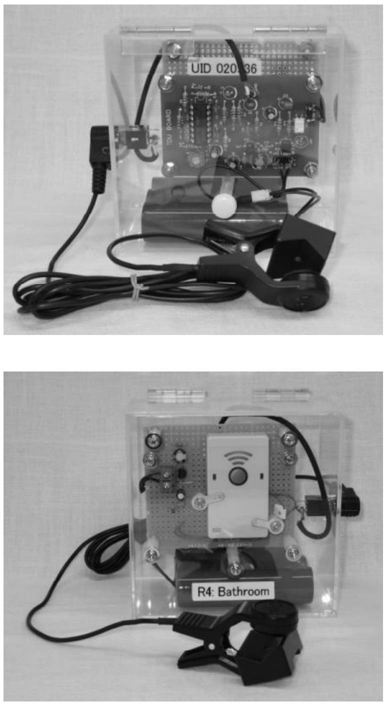


Figure 2. Prototype of the water flow sensor which consists of a vibration microphone, a sound-activated switch (the upper image), an active RFID tag (the lower image), and a battery.

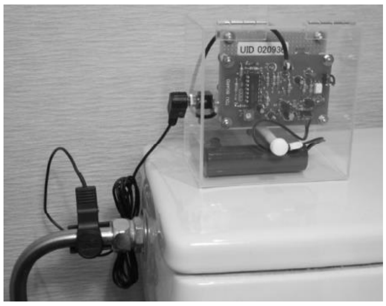

Figure 3. Vibration microphone clipped to the water pipe to the flush tank of a toilet.

used because ID codes are transmitted steadily at one-second intervals while the water is running. The received ID codes are accumulated at one-hour intervals to obtain a distribution of the duration of tap water use for each faucet. On the other hand, the time when the ID code was transmitted from the motion sensor indicates the resident's stay in the house. The received ID codes are also accumulated at one-hour intervals to obtain the frequency distribution of access to the sensor, in order to estimate how many hours the resident was at home by the hour. The reasoning program judges the health condition of the resident based on the distributions of the duration of tap water use for each faucet and the frequency distribution of access to the motion sensor.

## IV. Implementation and Experimental Results

The monitoring system was installed in a real housing environment and an experiment was conducted to see whether the sensor system can acquire the time and frequency of water


Figure 4. Front side of the IR motion sensor (an IR sensor module with a Fresnel lens and an active RFID tag at the back side).

Figure 5. Small computer with an RFID reader inserted in its USB port.

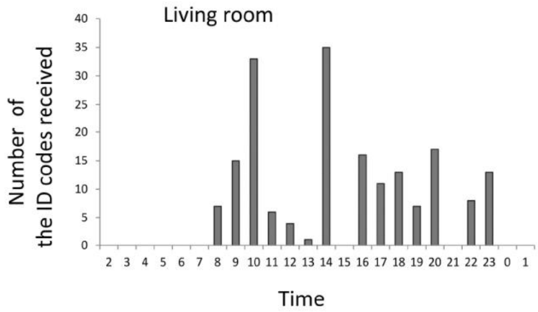


Figure 6. Frequency distribution of the resident's access to the living room.

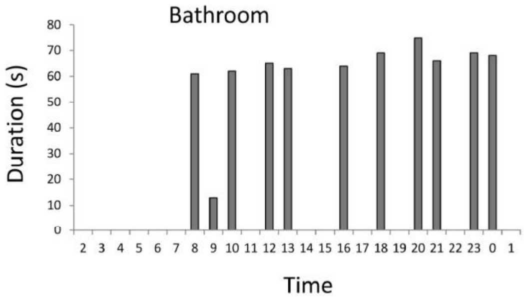


Figure 7. Distribution of the duration of water flow at the toilet's flush tank.

use from the resident's quotidian activities. The house had a living area of 108 square meters (roughly 15 m by 8 m) and the resident was a 68-year-old man. The IR motion sensors were placed on a cabinet in the living room. The water flow sensors were set at the kitchen sink, the washroom sink and the toilet's flush tank. The maximum distance between the RFID reader and the sensors was 8 m. First, the sensitivity and reliability of the water flow sensors were checked. The sensors could detect gently running water, such as would be poured into a glass.

Figure 6 illustrates the frequency distribution of the resident's access to the living room. The horizontal axis of the graph denotes the time at one-hour intervals, starting at 2 a.m. The vertical axis shows the number of times ID codes were received from the IR motion sensor. The sensor was placed on a cabinet in the corner of the living room connected to the corridor; thus, the motion sensor was activated only when the resident went in and out of the living room along the corridor. The sensor transmitted its ID code twice at one-second intervals, each time the resident passed it. The number is proportional to the frequency of access to the living room. Based on the time stamp of the received ID codes from the motion sensor, it can be seen that the resident got up at around 8 a.m. and went to bed at around 1 a.m. During the day, he was in the house and followed his daily routine. From the frequency distribution, the time zone when the resident went out can be estimated, and is used to reduce uncertainty in deducing health status based on data from the water flow sensors.

Figure 7 illustrates the distribution of the duration of water flow at the toilet. The horizontal axis of the graph denotes the time at one-hour intervals starting at 2 a.m. The vertical axis shows the duration of water use in seconds. The water flow sensor was set on the water pipe connected to the toilet's flush tank in the bathroom. The flow sensor transmitted its ID code at one-second intervals while water was flowing into the flush tank; it took about 60 seconds to fill the tank. The graph shows that the resident urinated 10 times on this day, at an average interval of 1.7 hours.

Figure 8 is a graph of the duration of tap water use at the kitchen. The water flow sensor was set on the water pipe connected to the sink's faucet. High-use periods were observed three times on this day. This implies that the resident used tap water for preparing meals in the morning, at around lunch time, and in the evening. The total time of water use was relatively short because the house is equipped with a dishwasher.

Figure 9 is a graph of the duration of tap water use at the washroom sink. The water flow sensor was set on the water pipe connected to the sink's faucet. This sensor is intended to detect quotidian activities for maintaining physical cleanliness. In other words, this sensor detects activities such as face washing, and brushing of teeth. The volume of water used at the washroom sink was not large because washing a face does not require so much water. The graph shows the washroom sink was used at around 9 in the morning. This implies that the resident used tap water for activities such as brushing his teeth and washing his face. It also illustrates that he performed activities, such as hand washing during the day and rinsing his mouth around midnight.

The reasoning program regards the duration of water use at each interval as one activity if the duration is above a fixed

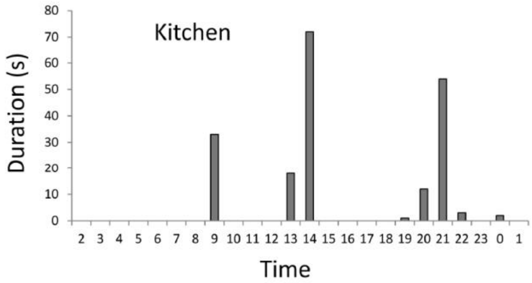


Figure 8. Distribution of the duration of tap water use at the kitchen.

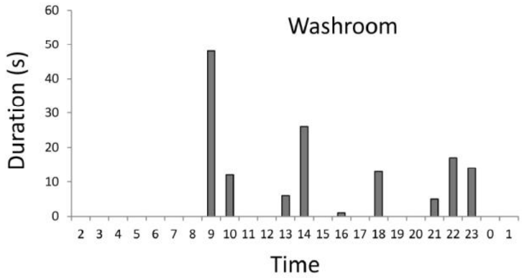


Figure 9. Distribution of the duration of tap water use at the washroom.

threshold of time. When the number of quotidian activities coincides with given criteria, it is assumed that there is some problem with the resident's physical condition. The criteria for judgment were created based on the model of normal water use, which was derived from the medical knowledge and regularity of daily living activities, as mentioned in Section 2.

In order to confirm the criteria for reasoning, we asked three solitary elders to use the monitoring system. The two of them (denoted as A and B, in Table I, II, and III, respectively) are 86 and 91 year-old women in good health conditions. By good health conditions we mean these elders are not under a doctor's care. Although they are living alone, their relatives visit their homes sometimes. The third elder (denoted as C) is a 92 years-old man with the early stage of dementia, and hypertensive condition. He takes an anti-hypertensive drug. There is no relative to visit him and the care giver visit him regularly. In the case of the two women (A and B), the monitoring system has been set in their housing for nearly one year, and the man (C) for three months.

It is said that humans urinate an average of six to eight times a day; thus, if an individual makes much less or much more frequent use of the toilet, then some illness or problem can be suspected. If one wakes two or more times before dawn to urinate it can also be a sign of a poor state of health. Therefore, Table I shows the average frequency of the water use per day at the bathroom in each housing and the average frequency is based on the latest one month measurement. The average frequency of the bathroom use for A was 8.71 times with standard deviation (STD) 2.23. The average frequency before dawn (from 2 a.m. to 5 a.m.) was 1.54 with STD 0.85. In the second elder's case (B) the average frequency was 6.93 with standard deviation 1.75. The average frequency before dawn was 0.72 with STD 0.53. In the case of the

TABLE I. Frequency of water use at the bathroom.

| | All day | | Mid night | |
|---|---|---|---|---|
| ID | Average | STD | average | STD |
| A | 8.71 | 2.23 | 1.54 | 0.85 |
| B | 7.03 | 1.93 | 0.72 | 0.53 |
| C | 13.5 | 2.29 | 1.84 | 1.18 |

TABLE II. Peak time of water use at the kitchen.

| ID | Breakfast | Lunch | Supper | Percentage of the day |
|---|---|---|---|---|
| A | 7.6 | 13.2 | 18.2 | 74 |
| B | 9.0 | 11.8 | 18.7 | 100 |
| C | 8.8 | 12.3 | 18.4 | 63 |

man (C), the average frequency was 13.5 with STD 2.29. The average frequency before dawn was 1.84 with STD 0.85. These numbers suggest that his micturition is affected by some disease.

At mealtimes people use a large volume of water at the kitchen for cooking and washing dishes. Time periods when the use of kitchen tap water is high appear in the distribution graph of water use, and are very likely to be observed in the morning, at around lunchtime, and/or in the evening. Table II shows the average peak time of the water use at the kitchen in the three time zones: breakfast time (6 a.m. to 10 a.m.), lunchtime (11 a.m. to 3 p.m.) and suppertime (4 p.m. to 8 p.m.). The fourth column of Table II presents the percentage of the number of the day when a peak time appears in every time zone. If the day when a peak time appears two times is added to the number the percentage gets up to 99 percent. This percentage means people have a strong regularity regarding to meals.

If people are healthy, they usually wash their faces and rinse their mouths when they get up in the morning, or before they go to bed at night. They sometimes perform activities such as hand-washing during the day to keep themselves clean. Table III shows the average amount and frequency of water use by the day at the washroom in each housing, which is based on the latest one month. In the case of A, the frequency of water use was few. In other cases, the frequency was about four time, and the average amount of running time of water was from 200 to 500 seconds. According to interview with the relative of A, she seems to use often the faucet near the bus tub for washing her hands and so on. As you know Japanese bus tubs are in their own spaces separated from the toilet, and are provided with a place and faucet for washing the body. In the case of C, he used much water at the washroom. He seems to have often washed dusters and so on. The amount and frequency of water use at a washroom seems to be dependent on the resident's lifestyle. Regarding to water use at a washroom sink, more observations in various home environments should be conducted to determine subtle criteria for generating automatic

TABLE III. Frequency and amount of water use at the washroom.

| ID | Average frequency | STD | Volume (unit: second) |
|---|---|---|---|
| A | 0.71 | 0.79 | 45 |
| B | 4.0 | 2.38 | 193 |
| C | 4.47 | 1.83 | 507 |

Report on Daily Living Activities
Client ID : R4M60001 Date : 2/12/2017

- Urination : Normal
 (Time Log of Water Use: 10 12 15 17 18 19 21 22 0)
- Kitchen Work : Normal
 (Time Log of Water Use: 10 11 15 17 18 19 20 21 0)
- Keeping Cleanliness : Normal
 (Time Log of Water Use: 10 11 12 0 1)
- Movement in & out of Living room
 (Time Log of Movement: 9 10 11 12 13 15 16 17 20 21 22 23 0 1)

Figure 10. Example of an e-mail message.

alert messages.

The criteria for judgment were created based on the results from these observations at three elders' homes, the medical knowledge, and the regularity of daily living activities. A brief outline of the criteria is as follows.

- If the frequency of urination is greater than twice in the night (from 2 a.m. to 5 a.m.), there is an assumption of "something wrong".
- If the resident remains indoors during the day time and
  - the frequency of urination is lower than 5 times or greater than 11 times; "something wrong".
  - the peak time of water use at the kitchen is less than twice; "something wrong".
  - the frequency of water use at the washroom is less than once; "something wrong".
- If the resident is out of the house for a long time, then the numerical values for these criteria are reduced in proportion to that time.

Each night at 2 a.m., the program judged the resident's physical condition from the criteria and sent out a daily report to appointed addresses by e-mail. In this experiment, the relatives, the caregiver, and the author were specified as the e-mail addressee. At same time all the data gathered to the monitor system was saved at the data server in the author's office, and was deleted from the monitor system. Figure 10 shows an example of an e-mail message, which consists of four items: "Urination", "Kitchen Work", "Keeping Cleanliness" and "Movements in & out of Living room". The first three items consist of a judgment, and the list of time of major water use on the day. The fourth item includes only the list of time of the resident's movements in the house. If each quotidian activity coincides with the given criteria, the judgment was denoted as "Something Wrong" and otherwise, as "Normal".

## V. CONCLUDING REMARKS

We proposed a health monitoring system, which evaluates the health status of solitary elderly based on daily living activities. The system monitors three quotidian activities that are closely involved in maintaining a healthy lifestyle: urination, kitchen work, and practices for good personal hygiene. These quotidian activities are usually accompanied by water use, and there are some regularities in water use, which correlate with the health status of the resident. This is the reason why we paid attention to the three quotidian activities.

There is a demand for a reasonably priced, noncontact sensor system that can directly recognize these quotidian activities. In addition, the monitoring system should be affordably installed into any type of housing. To meet these demands we proposed the water flow sensor with a vibration microphone that can be easily clipped to a water pipe leading to a faucet. We made a prototype of the monitoring system from electronic parts that are all available in the market.

The prototypes have been installed in three volunteer's housing in order to confirm the criteria for reasoning. Although useful results were derived from the experimental use, regarding to water use at a washroom, more observations in various home environments should be conducted to determine subtle criteria for generating automatic alert messages.

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# Involuntary "Deep Breathing" by Posture-Respiration Feedback Control System

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***Abstract*— When a person bends his/her back, it makes it easier to exhale the air from lungs but difficult to inhale. In contrast, when a person lean his/her back, it makes it difficult to exhale but easier to inhale. This simple fact opens the possibility to regulate human breathing involuntary with posture control. We developed a posture-respiration feedback regulation system and tested the efficacy of the proposed architecture. The results indicate that "deep breathing" was successfully induced when the posture control was precisely synchronized with the user's own respiration.**

***Keywords-breathing control; posture feedback; respiration.***

## I. INTRODUCTION

Breathing control has numerous benefits on our daily life. A voluntary breathing control improves the task performance [1], alleviates anxiety [2]-[4], and appropriately controls the autonomous nervous system activities such as heart rate and blood pressure [5]-[8], and even immune functioning [9]-[11]. On the other hand, breathing-related disorders appear to be a great danger to our daily life, e.g., obstacle sleep apnea is a prominent risk factor of cardiovascular disease [12].

To obtain the benefits of breathing control, a variety of methods have been developed, such as sports, yoga, religious meditation, etc. In addition to such voluntary breathing control, in a clinical setting, passive ventilation equipment has been developed and has proven its great efficacy [13][14].

However, there are still some limitations in the breathing control methods, both voluntary or passively. First of all, voluntary breathing control requires much effort and concentration so it is difficult to continue over a long period of time, especially for the elderly. On the other hand, the passive ventilation, such as continuous positive airway pressure (CPAP) [13] and adaptive servo-ventilation (ASV) [14] requires patients to be fitted with a nasal cannula or respirator, so it cannot be suitable for daily use at home.

Therefore, in this study, we propose an alternative method for semi-passive breathing control method via posture control. The idea is based on the simple fact, as follows: when a person bends (rounds) his/her back, it makes it easier to exhale the air from the lungs, but more difficult to inhale. In contrast, when a person leans his/her back, it makes it difficult to exhale, but easier to inhale. This simple fact opens the possibility to regulate human breathing involuntary with posture control.

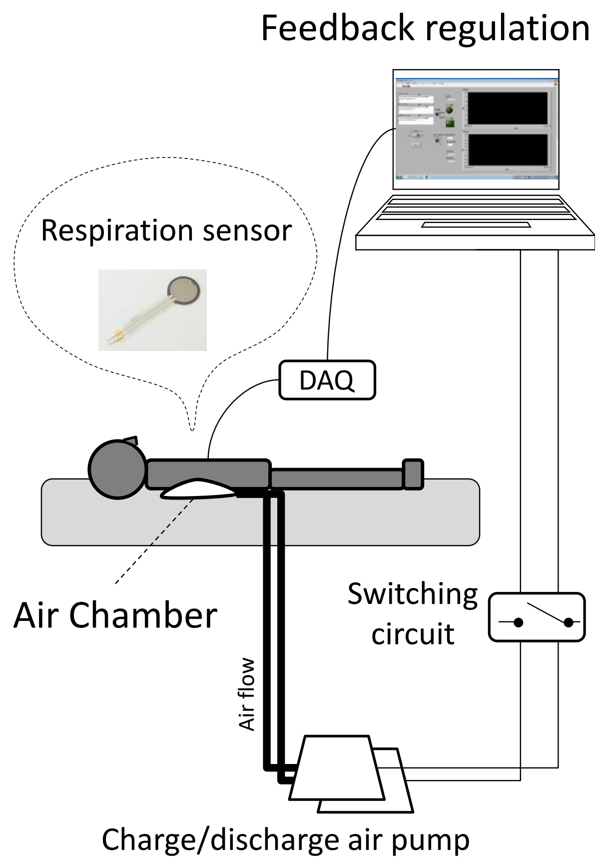


Figure 1. Schematic diagram of the posture-respiration feedback control system.

Then, we developed an architecture which forces to change the posture of the user synchronously his/her own breathing cycle.

In the next section, the architecture of the developed system, the procedure of the experiment to test the efficacy of the system are described. The following sections describe the results of the experiment, discussion, and conclusion.

## II. METHOD

Figure 1 shows the architecture of the posture-respiration feedback regulation system. It was basically the same architecture with our previous work as the respiration is

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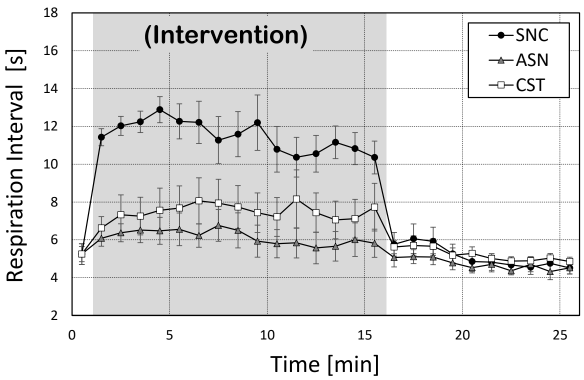


Figure 2. Change in the respiration interval (mean ± S.E.M).

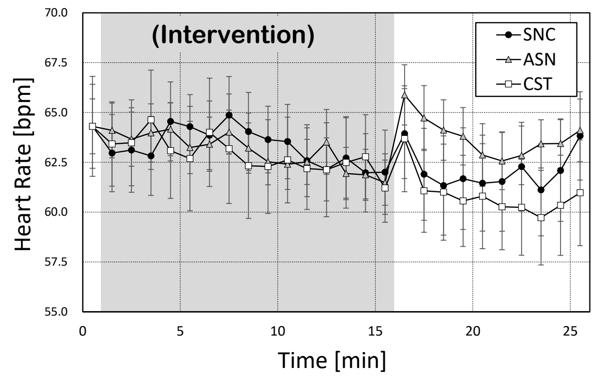


Figure 4. Change in the heart rate (mean ± S.E.M).

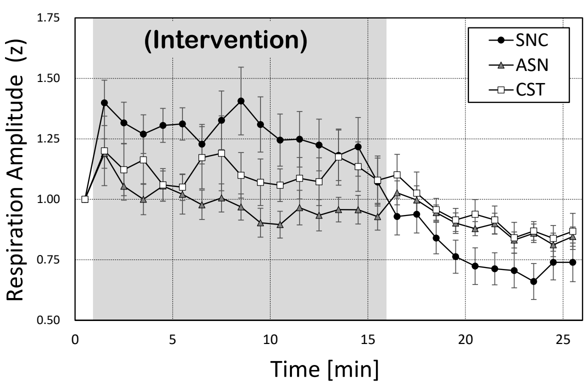


Figure 3. Change in the respiration amplitude (mean ± S.E.M).

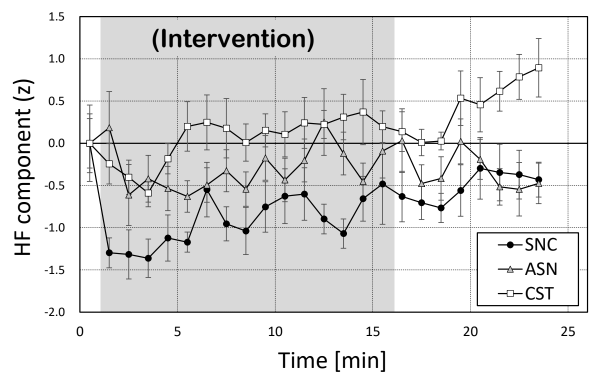


Figure 5. Change in the HF component (mean ± S.E.M).

detected by a pressure sensor, the analog signal from the sensor is converted to digital format with DAQ, the adaptive feedback (described later) is achieved with an interactive software (LabVIEW) which controls the inflation/deflation of the air-chamber via switching circuits to intervene in the posture of the user [15]. The silicon-made air-chamber placed beneath the subject's back deflates/inflates according to subjects own respiration cycle. For example, when a subject starts inhaling/exhaling, the air-chamber starts to inflate/deflates so as to assist his/her inhalation/exhalation of the air into/from the lungs. We assume such an intervention to posture would make subject's breathing deeper and longer, and leave them more relaxed in terms of body and mind.

To test this hypothesis, we conducted an experiment with three different respiratory intervention conditions: 1) the air-chamber inflates/deflates synchronously with subject's inhalation/exhalation (namely, "SNC" hereafter), 2) the air-chamber asynchronously inflates/deflates with breathing, as such it inflates/deflates when subject exhales/inhales (namely, "ASN"), and 3) the air-chamber inflates and deflates with a certain and constant rhythm (namely, "CST"). In SNC and ASN cases, the inflation and deflation cycle of the air-chamber is precisely decided with each one of the subject's respiration, whereas, in CST condition, the cycle of the air-chamber is set to the same duration with each subject's mean deep breathing cycle which was obtained in advance.

Ten healthy male university students (aged 22-24) participated in this study. The experiment consisted of 1 minute initial rest period, 15 min of intervention period, and 10 min of another rest period (recovery period).

Respiration of the subjects were measured by a thermistor sensor. Electrocardiogram (ECG) was measured with a biological amplifier to evaluate the cardio-physiological functioning by the posture-respiration intervention.

The experiment was conducted such that each participant went through all three conditions in a randomized order.

For statistics, paired-t test was performed with p-value of 0.05 as the level significance.

The study was conducted in accordance with ethical principles and informed consent was obtained for all subjects. The study was approved by the ethics committee of Nagaoka University of Technology. It should be noted that the number of participants was limited less than 10 and they were required to be among the healthy population because this is the very first pilot study to examine the physiological effect of our proprietary developed feedback architecture.

## III. RESULT

Figures 2 and 3 show the change in the interval and the amplitude of respiration. As expected, the respiration was longer ($p < 0.01$) and deeper ($p < 0.01$) in SNC than other two conditions. In ASN, subjects' breathing was remarkably restricted. In the meantime, in CST condition, the change in respiration was depicted in between SNC and ASN.

Figures 4 and 5 show the change in the heat rate (HR) and the high frequency (HF: 0.15 - 0.40 Hz) component of the heart rate variability. As seen in these figures, HR did not differ among conditions ($p > 0.05$) in the intervention period. Meanwhile, HR in the recovery period in ASN was significantly higher than other conditions ($p < 0.01$), and it reached a higher value than the initial rest period (overshoot). HF in SNC was the lowest in the intervention period and thereafter ($p < 0.01$).

## IV. DISCUSSION

In this study, the impact of posture-respiration feedback system on respiration and cardiac autonomous system function was investigated. As expected, in SNC where the inflation/deflation of air-chamber was synchronized (i.e., no phase delay), respiration was made longer and deeper. This implies that our developed system can induce "deep breathing" unconsciously.

On the other hand, in ASN where the posture regulation was administered asynchrony with respiration (i.e., phase delay is 180 degree), there was no change in the interval and amplitude. Moreover, in the recovery period, a sort of overshoot of HR was observed in ASN. HR overshooting is frequently observed in the recovery period after mild excise [16]. It occurs to meet the requirement to balance the greater oxygen cost of fat catabolism during the early recovery period. It might be rather speculative but if the HR overshoot seen in this study share a part of the same background with that of after exercise, it might reflect the lack of oxygen in the intervention period as such, despite of the large effort of doing respiration, whether it be intentional or unconscious, ASN condition made it difficult and worsen the efficiency of ventilation, and and this phenomenon mislead the body into believing the concentration of air oxygen is "low", resulting in a higher requirement for oxygen after intervention (in "normal" circumstance).

In CST, the impact on respiration and cardiac autonomous system were marginal compared to SNC and ASN, and the breathing seemed to be gradually entrained with the constant rhythm. The cycle of air-chamber movement in CST was fixed at the same duration with each subject's "deep breathing", so subjects might modulate their breathing cycle voluntary to their deep breathing. However, the interval and amplitude of the respiration in SNC reached far beyond CST. In this sense, our developed posture-respiration intervention architecture have demonstrated the prominent impact on the respiration.

On the contrary, HF in SNC was strongly suppressed as shown in Figure 4. The HF component of the heart rate variability has been frequently taken as an index of cardiac parasympathetic nervous system activation [17]. However, one cannot interpret the result of our study as SNC condition suppress parasympathetic nervous activity. Since it is the respiration that we intervene, HF component is not just a naïve representation of parasympathetic nervous system activity. More detailed physiological study is needed to further discuss on this phenomena.

## V. CONCLUSION

In summary, we tested the efficacy of our developed posture-respiration intervention system in a manner of real-time feedback regulation. The results indicate that "deep breathing" was successfully induced when the posture control was precisely synchronized with user's own respiration. Regarding the impact of cardiac function, HR overshoot was observed as the after effect of asynchronous regulation. Further physiological study promises to reveal the underground mechanism of the impact of our system.

## ACKNOWLEDGMENT

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# Mobile Low Cost System for Environmental Monitoring in Emergency Situations

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***Abstract*— Each year forest fires destroy large forest areas damaging the ecosystem they held. When these fires occur in residential areas, they also present a big danger to the inhabitants of the area, who must find a way to escape themselves from fire. Emergency services should also be able to determine possible access and evacuation routes. It is very difficult to have deployed networks that remain active, so in this paper, we propose the use of citizens' private vehicles to install sensor nodes capable of collecting data from the environment and send this data, through the telephone of their drivers to a database. This database can be consulted by citizens and emergency services. The system consists of a wireless sensor node equipped with several sensors that will communicate via Bluetooth with the Smartphone driver. A Smartphone 3G / 4G connectivity is used to send alarm messages, through Internet, to a central database. Finally, the system is tested in different conditions to check its effectiveness. With the use of this system, emergency services would be able to define escape routes for citizens who might be caught in a fire.**

***Keywords-environmental monitoring; arduino; Android App; sensors; fire detection; mobile nodes; emergeny situations.***

## I. INTRODUCTION

Nowadays, the world is suffering from numerous wildfires. Year by year, thousands of hectares are destroyed. The consequences are terrible for the ecosystem and the economy of that area. In the most serious cases, forest fires cause the death of the inhabitants of the affected zone [1]. Active fires in California (USA), Portugal and Spain (EU) have killed more than 60 people [2][3]. Part of the people who died in those fires did so trying to escape from the fire by using rural roads. Unfortunately, the fire managed to trap them while they were on the road. This type of accidents is very hurtful for people as many of them could have been avoided. Detecting a fire on time and knowing the best escape routes to avoid it are of great importance in order to save the life of both citizens and fire fighters.

There are many systems that are employed for ambient and environmental monitoring [4]; however, most of them are developed for cities or are centered in measuring air pollution [5][6]. Cities allow an easy access and connection to the electricity grid for the devices employed for those purposes but, rural areas present more difficulties. Although there are many wildfire detection systems, they are based on image processing [7][8] or they require the deployment of Wireless Sensor Network (WSN) nodes over the expanse of the forest to obtain information on temperature and humidity [8]. These solutions are costly because they need a great quantity of nodes to be deployed over thousands of hectares in forest where access is very difficult. Moreover, the effort of charging the batteries of all nodes would be massive.

Deploying fire detection systems in vehicles can help to avoid accidents where the occupants of a vehicle get trapped by fire by alerting the driver. In this paper, a cooperative system for vehicles that measures ambient conditions and the state of the vehicle is presented. The system monitors air quality, the presence of fire, Global Positioning System (GPS) position of the vehicle and the state of the vehicle, meaning whether the vehicle is upside down, blocking the road or if it is functioning as it should. The information from all vehicles that get installed the system is then forwarded to a server in order to determine the best escape routes considering the roads of the area. This system can be employed by civilians and emergency responders in order to ensure their safety in light of extreme wildfire related circumstances.

The rest of this paper is structured as follows. Section II shows some previous works where previous proposals are presented. This system is composed by an electronic device based on an Arduino board, a smartphone and several software parts that control its operation. Thus, Section III shows the design of our prototype and it implementation. The results of our test bench to check the proper operation of our low-cost system are shown in Section IV. Finally, conclusion and future works are exposed in Section V.

## II. RELATED WORK

The use of sensors for monitoring purposes is increasing constantly. Particularly, many are being employed as part of WSN to monitor environmental parameters. Ferdoush et al. employ in [10] Arduino and Raspberry Pi open source-hardware for environmental monitoring purposes. Their system includes a database and a web server to store and access the temperature and humidity data gathered by the sensor. Internet of Things (IoT), cloud computing and a GPS module are employed in [11] to monitor climate change and its effects. Another environmental monitoring system that employs WSN to gather data is presented in [12]. The presented sensing station costs around 900€ and employs a solar panel and two batteries as a power source.

As a result of the increasing cases of wildfires, the number of wildfire detecting and wildfire fighting systems are on the rise. Many of them employ cameras to detect when a fire has started. Bosch et al. present in [13] a system that employs thermal imaging to detect wildfires. They use a

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WSN with sensors composed of a visible and a thermal camera and a motor, in order to be able to cover wider areas. The cameras do not need to be high resolution nor does the system require knowing the temperature. When a fire is detected, the system sends an alarm. It also sends an alarm when the wildfire is increasing in size or when it is persistent. This technique is also used to determine the presence of anomalies as diseased in grapes and/or its leaves [14]. Other solutions are employed after the fire detection and progress monitoring, such as the one proposed in [15]. The system is a co-operative control framework for Unmanned Aerial Vehicles (UAV) and Unmanned Ground Vehicles (UGV). It employs a hierarchical structure and It can design mission plans, allocate tasks and manage the activities of all the vehicles.

The concept of using cars as a source for sensing, data transfer and storage, computing, location and providing information and entertainment is getting more popular nowadays. Abdelhamid et al. name it in [16] as Vehicle as a Resource (VaaR). They also introduce the challenges of such technologies such as privacy, data quality or redundancy. One of its applications is monitoring different aspects in a car. In order to do so, sensors are being highly employed. Specifically, avoiding, assessing and aiding emergency situations are some of the most researched topics. A system that detects fatigue in drivers is presented in [17]. The system employs several sensors that measure movement, pressure, temperature, proximity and shocks to determine when the driver could be tired. If the system detects fatigue in the driver, a sound alarm, that the driver must disable pressing a button, is generated. A system that detects and estimates the severity of road accidents is proposed in [18] by Fogue et al. They consider vehicle and impact speed, state of the airbag and vehicle type. Impacts, high temperatures and water inside the cabin are detected by the sensors deployed inside a car on the system designed in [19]. In case of accident, the system forwards a message to a police station or hospital, and a family member. The message contains the location of the vehicle and its registration number.

Although systems that monitor the environment, detect fires and help drivers in emergency situations exist independently, there is no other system that combines all three applications into one system that helps drivers to detect when a wildfire has started and provides an escape route.

## III. System Description And Implementation

This section explains the architecture that includes our mobile low cost system for environmental monitoring in emergency situations. It also includes a detailed explanation of system and its main parts.

### A. *System description and propodsed architecture*

In a forest fire near to residential areas, one of the main goals is to ensure the evacuation of people through a secure way. For this reason, it is mandatory to establish a set of parameters to be monitored and shared along the network. After analyzing the last forest fires in Portugal and Spain, with fatalities, we have established the following parameters:

- GPS position and vehicle tracking.
- Vehicle status, i.e., if it has suffered an accident or it is blocking an escape routes.
- Presence of fire.
- Presence of Carbon dioxide or a poor quality of air that difficult the breathing.
- The system must be installed in a vehicle, without having to make any type of modification in its manufacture.

The proposed architecture is based on a set of mobile nodes provided with a set of sensors. These mobile nodes are connected via 3G / 4G technology (since we use the smartphone to transmit the data) to the Internet in order to send data to the central database unit (CDBU). CDBU contains the data from all vehicles that compose the cooperative network and provides data to a web site that dynamically changes as a function of the received data. To tag a route as available, the system has to consider the number of vehicles is driving along this route. In a scenario where all vehicles have this system, it is easy to obtain this parameter. Furthermore, the system should provide some alternative route to facilitate evacuation. The information is easily accessible by emergency/rescue services and citizens. There, we can see in different colors the possible available routes. The data gathered by sensors is locally stored in each node and shared through Internet. Finally, these data should be stored in a CDBU. The proposed architecture is shown in Figure 1. Although, the system is currently based on 3G / 4G networks since they are nowadays standardized and extended among users, it can be easily migrated to 5G technology when it will be standardized, deployed and extended among users. Additionally, the system should be able to send some alarm message (as a broadcast message or similar) in order to quickly inform about the problems in the escape route or rescue way. To process this alarm, we have developed a control algorithm that takes into account the data from all sensors (see Figure 2). As one can see, the node sensor is waiting to receive some connection request. When a user, through his smartphone requests to connect to it, the node accepts its connection. At this point, the node is ready to receive the location and current time. Data are directly extracted from the smartphone and locally stored on the node. Periodically, the node checks that the Smartphone is still available. If not, the node will log an error and return to the initial state. If any of the measured parameters exceeds the established security thresholds, the system saves the data and creates a text message with the detected event information.

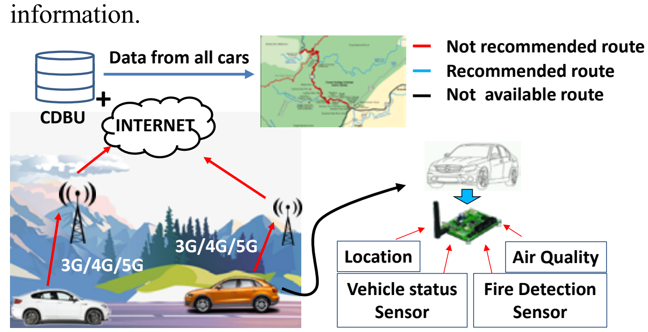



Figure 1. Proposed Architecture for the system.

### B. Design and implementation

In order to design the system, we have set up some premises that this system should satisfy. The system should be:

- Cheap and easily installable in a vehicle.
- Versatile and should be independent from the vehicle brand.
- Able to take data on geographical position from the smartphone the driver has.
- The data exchange between drivers' smartphone and the system should be through permanent Bluetooth connection.

The whole system (see Figure 3) is composed by a microcontroller board and a Bluetooth module, which is connected to the Smartphone that drivers usually have. There are several possible commercial microcontroller boards but in our case, we have used an Arduino module since this platform is very cheap and easy to configure. The system works as follows. On the one hand, the smartphone receives the GPS positioning data from the satellites intended for it. This information is sent to our device via Bluetooth combined with the reference of the current time. In this way, our device can keep a record with the data from sensors and store the vehicle GPS position with and actual reference time in a Secure Digital (SD) card. On the other hand, when a sensor detects some anomaly in the sensors value, it sends an alarm code via Bluetooth to our mobile phone, which the Android application recognizes and acts accordingly.

The system is composed by a set of sensor that Table I summarizes. The connections schema of the system and the different modules used to compose our mobile low-cost system for environmental monitoring in emergency situations is shown in Figure 4.

### C. Android Graphical User Interface

In order to carry out the communication between the Arduino module and the Smartphone, we have developed an application called *CarAppCident* for the Android platform with a simple user interface, prepared for future incorporation of new sensors.

After installing our application, we should run it. We will see the main screen (Figure 5a) where we can press *"Bluetooth Device"* to start the scan for available Bluetooth devices. After pressing it, we access to a black screen with a list of detected devices (Figure 5b). From this list, we can select our Arduino device, which is identified as *ArduinoR*.

If we click on the name of the device, we will be connected and prepared for sending and receiving information. Once connected, our Smartphone starts sending location and time data to our Arduino module since the application is running in the background. At this time, we could stop managing the application. However, if we want to know our position we can press the button "My Position" and the coordinates, i.e., latitude, longitude and height, of our position will appear. In addition, an approximate address to where we are is provided. This is a quick way to self-locate, if this information should be provided for requesting help or in any other situation (see Figure 6).

In addition, with the indicator of passengers (function that will be enabled in future versions), the system can save the data in regard to the number of vehicle's passengers. This information can be useful when emergency services should rescue a damaged vehicle and determine if all of the vehicle's passengers have been located and assisted.

To program the necessary code to gather data from sensors and establish the connection, the App Inventor application has been used. One of the main parts of the program is the Bluetooth connection (see Figure 7).

Before pressing "Bluetooth Device" button, the smartphone check if Bluetooth clients are available and displays them. If the connectivity with the Bluetooth client is lost or the device is no longer available, the system will shows us an error. After pairing both devices, the smartphone starts to send the time reference, GPS position and current address. As Figure 8 shows, each parameter is sent separately. Parameters are sent separated by a space since it is easy to be processed.

## IV. RESULTS

After the programming the system, we need to check its correct operation. To do it, the different sensors have been tested. This section shows the results obtained during the test bench.

### A. GPS position

The first test is focused on determining the geographical position of our vehicle. To do so, the vehicle where the system has been installed has performed a trip.

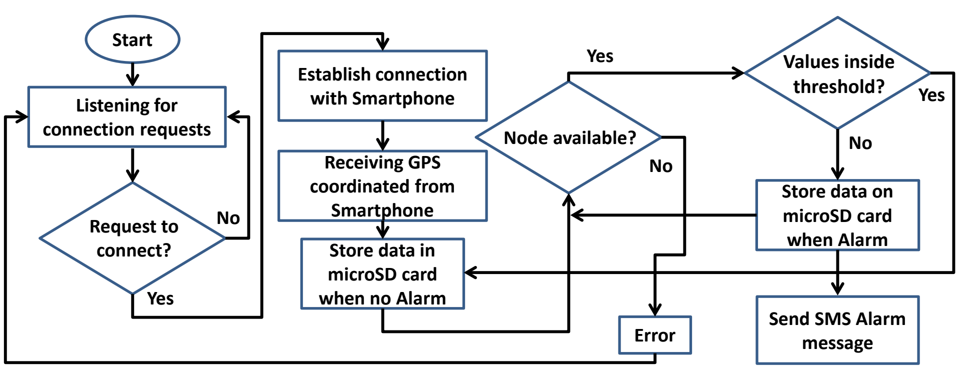



Figure 2. Operation Algorithm.

TABLE I. COMPOMENTS USED BY THE SYSTEM

| | Components used by the system | | | | | |
|---|---|---|---|---|---|---|
| Function | ***Data Processing*** | ***Air Quality*** | ***Fire presence*** | ***Gyroscope*** | ***Bluetooth*** | ***Data Storage*** |
| Component | Arduino UNO. rev. 3 | MQ-2 Sensor | KY-026 sensor | MPU-6050 GY-521 sensor | HC-06 Module | MicroSD module and MicroSD Card |
| Price ($) | 25 | 3 | 7 | 2 | 7 | 10 |

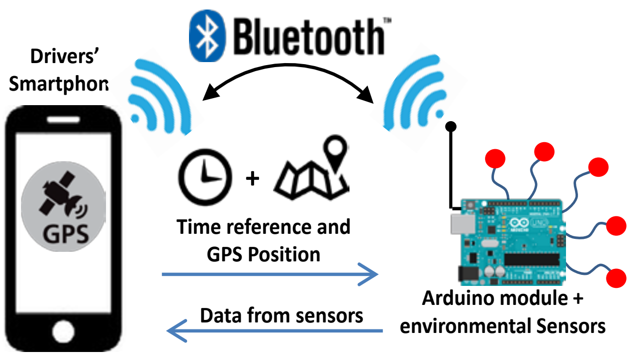



Figure 3. Schema of connection for the system.

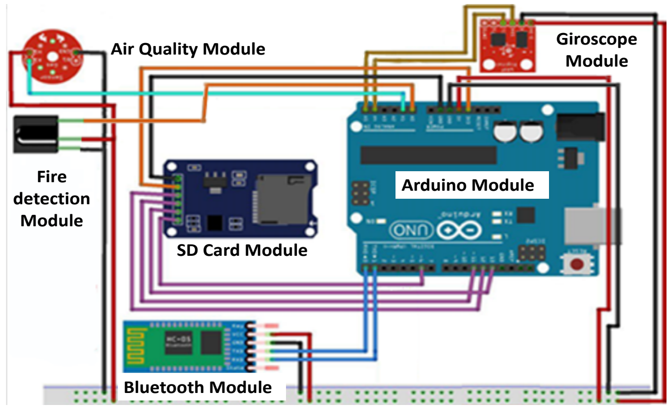



Figure 4. Microcontroller and sensors connection

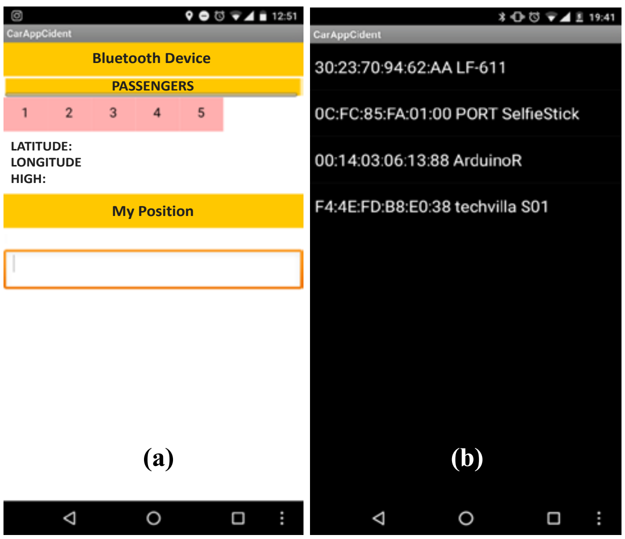



Figure 6. Main screens of CarAppCident application

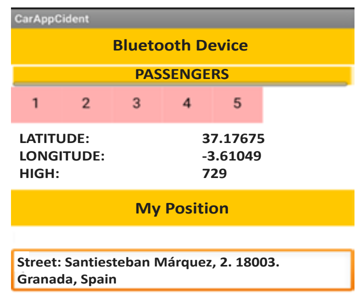



Figure 5. Position reception

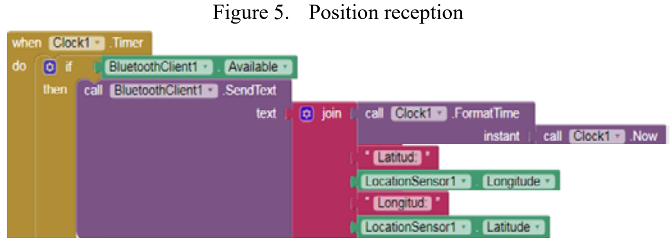



Figure 7. Program for sending GPS Position through Bluetooth

A smartphone with GPS connection has also been used to provide the data of latitude and longitude. Measurements are taken every 30 seconds. These data is sent to the Arduino module and stored as a file text in the microSD Card. An example of this text file is shown in Figure 9. Finally, the collected data has been placed on a map in order to see the path followed by the vehicle (see Figure 10).

## B. Vehicle status

To check how the gyroscope sensor works, the system is installed in a platform which emulates the movement of a car when it dumps. We emulate that a car has suffered an impact and has undergone a turn until it is positioned on one of its sides. The sampling frequency is 4 samples per second. The results obtained are shown in Figure 11.

As one can see, up to 3 seconds, our vehicle is in the rest position. From this moment, the vehicle begins to vary its position, making a sharp turn toward the +X-axis. We establish an alarm threshold (20º), from which we consider that the car has overturned. This type of sensors does not have an immediate response. As we can observe, when 7 seconds have elapsed, the system has exceeded the specified threshold. When 12 seconds have elapsed, both axes have exceeded the threshold and therefore the alarm is generated. In this case, the system has taken 9 seconds since the vehicle begins to vary its position until it blows the alarm due to a dangerous position. These values have been selected only for the purpose of presenting how the alarm is generated as a function of the car movement. However, these values are easily adjustable.

### *C. Fire detection*

As we explained before, the system should be able to detect the presence of fire in the surrounding areas of our vehicle and activate the alarm. The results offered by the sensor are shown in Figure 12. During this test, we kept the sensing far from the fire during the first 8 seconds. From this moment, we have approached the fire and stepped back from it several times. We could observe that when there is no fire, the voltage value of the fire sensor is approximately 4.92 volts while lower values meant that there was presence of flames near the vehicle, and therefore, the place where we were cannot be considered as a safe escape route. It is easy to see that the voltage registered by the sensors decreases when fire is detected near the car. So, we establish the threshold at 4.5V. From this point, the system will consider a fire is detected.

### *D. Smoke detection*

The operation of the smoke/gas sensor is very simple. When it detects some type of gas, specifically Liquefied Petroleum Gas (LPG), propane, methane, alcohol, hydrogen or smoke, the internal system of the sensor begins to warm up and its temperature increases, which implies an increase in the reading of the analog value. In addition, the sensor needs few seconds since it is started up until it is able to reliably take measurements. In order to test the operation of the sensor, our sensor is subjected to various bursts of butane gas. The results obtained are shown in Figure 13. As one can see, the sensor needs approximately 10 seconds to stabilize its resting value, which is around 0.8 V.

When the gas/smoke concentration increases near to our sensor, the voltage also increases. One can see two peaks at 80s and at 135s. The values of output voltage of sensor in the presence of gases detected are higher than 1.1V. So, we can establish the threshold at 0.85volts.

### *E. Alarm messages*

Finally, Figure 14 shows an example of a text message generated when fire is detected near to the car at a particular location. As noted, the message contains information about the event which generated the alarm, the time it was generated and the GPS location where this event was detected.

## V. CONCLUSION AND FUTURE WORK

In this paper, we have presented a mobile low cost system for environmental monitoring in emergency situations. The novelty of this system is that we use the private cars to have several nodes taking data from the environment. The system is composed by a sensor node, which is connected to a smartphone to take advantage of the 3G / 4G connectivity. According to our result, the system can be very useful to determine possible evacuation routes to rescue stranded citizens, in emergency situations, such as forest fires. In this way, many deaths of people who attempt fires along roads that are unaware of their condition could be avoided.

As future works, we would like to integrate some more sensors in the vehicle. These sensors will provide information to the emergency services about the vehicle status in order to better plan the rescue tasks

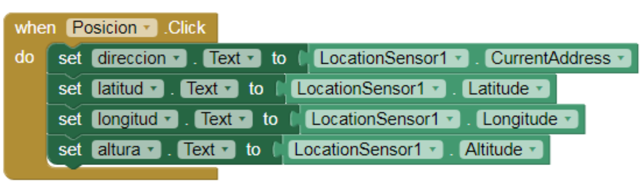
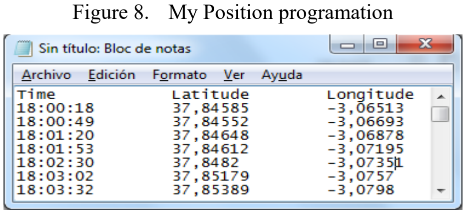



Figure 8. My Position programation



Sin título: Bloc de notas

Archivo Edición Formato Ver Ayuda

| Time | Latitude | Longitude |
|---|---|---|
| 18:00:18 | 37,84585 | -3,06513 |
| 18:00:49 | 37,84552 | -3,06693 |
| 18:01:20 | 37,84648 | -3,06878 |
| 18:01:53 | 37,84612 | -3,07195 |
| 18:02:30 | 37,8482 | -3,07351 |
| 18:03:02 | 37,85179 | -3,0757 |
| 18:03:32 | 37,85389 | -3,0798 |

Figure 9. Text file with GPS coordinate

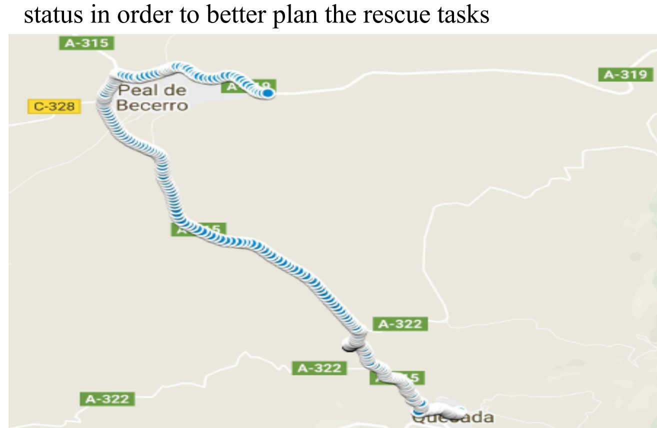



Figure 10. Position information placed on a map.

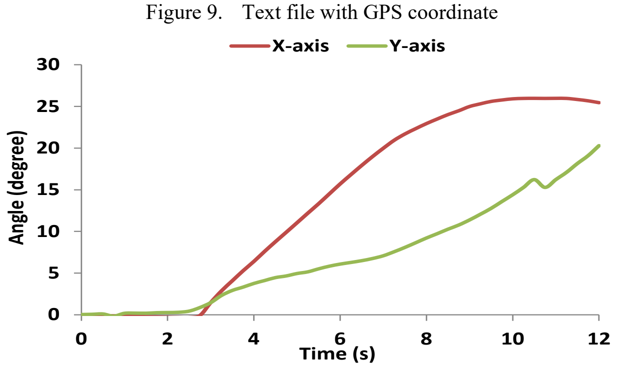



Figure 11. Measurements of vehicle position with measurements each 0.25s

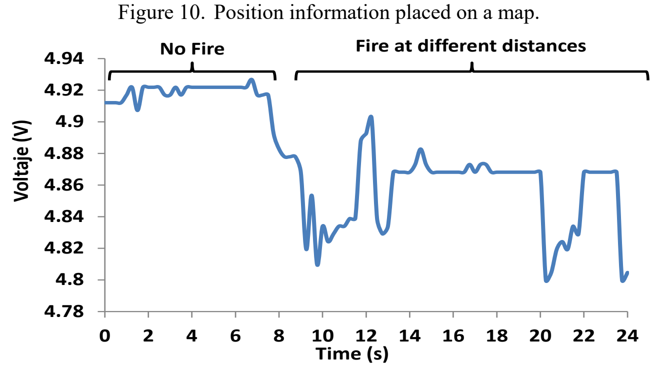



Figure 12. Measurements of fire detection

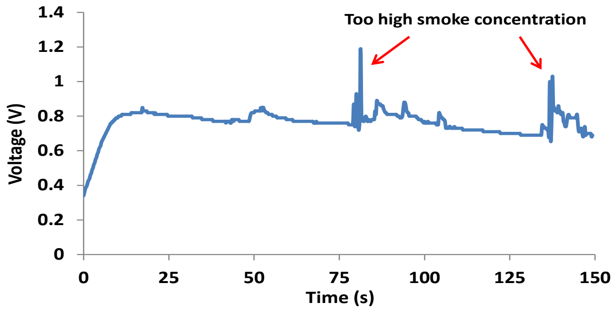



Figure 13. Measurements of smoke detection

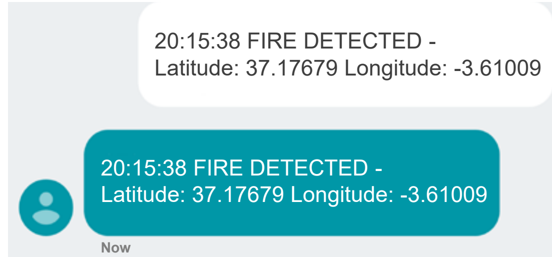



Figure 14. SMS reveived when fire is detected.

We would also ensure the security of data stored in the CDBU through the last techniques [20] to be sure that nobody uses them in a criminal way. Finally, the system is transmitting the data through 3G / 4G networks. As future actions, we would like change the connectivity to 5G networks [21].

## ACKNOWLEDGMENT

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# Proposal and Evaluation of a Data Transmission Method for Using Sound in Accurate Indoor Positioning

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*Abstract*— **This paper proposes a method to process the data representing the sound that is used to determine the indoor position of objects. A scheme is proposed and its theoretical validity is confirmed by numerical simulation using MATLAB. The scheme is to modulate a sound source based on information or data obtained before diffusion (spread spectrum) by an M sequence code. The experimental setup includes a speaker and a microphone, and the bit error rate is evaluated by changing experimental conditions such as the transmitting frequency and the order of the M sequence code. This fact leads to the realization of the system by sound, to provide both indoor positioning and sensor data transmission functions.**

***Keywords-Sound; Spread Spectrum; Data Transmission; Inaudible Sound; Indoor Positionng.***

## I. INTRODUCTION

Location information is one of the most important information, whether outdoors or indoors. Global Positioning System (GPS)/Global Navigation Satellite System (GNSS) has become a standard positioning system and its hardware and uses now involve large market. Although many kinds of positioning methods and systems have been studied and developed [1][2], there is no standard system to determine the position of objects or people in an indoor environment. At present, several systems may be selected, depending on the specific requirements of particular situation.

The authors have been studying a highly accurate indoor positioning system that uses sound. The velocity of sound is quite low compared with that of radio waves, so the problem of errors resulting from the timing of signal reception presents no severe difficulties, and it is easy to discriminate between direct sound and multipath sound due to reflections etc. This enables accurate positioning by the use of sound. If an additional data transmission function can be included in this system, so that transmission of both positioning and other information can be achieved with the same system components, the applicability and value of the system will be greatly enhanced.

At the first stage, we use ultrasonic waves and detect the time of reception by the voltage at the receiver. This can realize high accuracy, but requires an ultrasonic transmitter. This equipment is not in common use, which this could act as a barrier to the system coming into widespread use [3]. As a second stage, we used inaudible sound from a smartphone. In this system, a spread-spectrum sound source and a correlation calculation are used to detect the reception time at each microphone sensor. The position is then obtained from the time difference between sound reception at each receiver [4].

In the GPS/GNSS system, information such as satellite orbit data etc. are included in the radio wave used for positioning. It is thought that data can be similarly embedded in the sound used in this positioning system, as both radio and sound are wave phenomena. We are now investigating a realization of both of accurate indoor positioning and information data transmission, such as sensor data in one system.

This paper presents a method to embed additional information in the sound used for indoor positioning. A scheme using sound diffusion (Spread Spectrum (SS)) is proposed, and its validity is confirmed by numerical simulation in Section III. The experimental setup uses a speaker and a microphone and the transmission quality has been evaluated under a range of experimental conditions. It was shown in Section IV that data transmission can be achieved by the proposed method, which points to a system that has the dual functions of indoor positioning and data transmission.

## II. TARGET SYSTEM AND ADDED FUNCTION

### A. *Summary of composed indoor positioning system*

The principle of the indoor positioning system to which the authors will add a data transmission function is shown in Figure 1 [5]. The positioning principle of this system is based on the Time Difference Of Arrival (TDOA) principle.

The spread spectrum sound diffused by an M sequence code is transmitted from the positioning target to microphone sensors connected to each receiver. The timing in the received signal is detected by correlation calculation, and the time differences at each sensor ($t_1$, $t_2$, $t_3$) are obtained. The position of the sound source (positioning target) is calculated from the time difference data. The positioning principle is based on the difference between arrival times. The positioning principle is based on the differences between times of arrival. This method can yield quite high accuracy, with an error of less than a few centimeters. An example of the experimental results is shown in Figure 2. If the sound can include information, such as sensor data, the system can be used not

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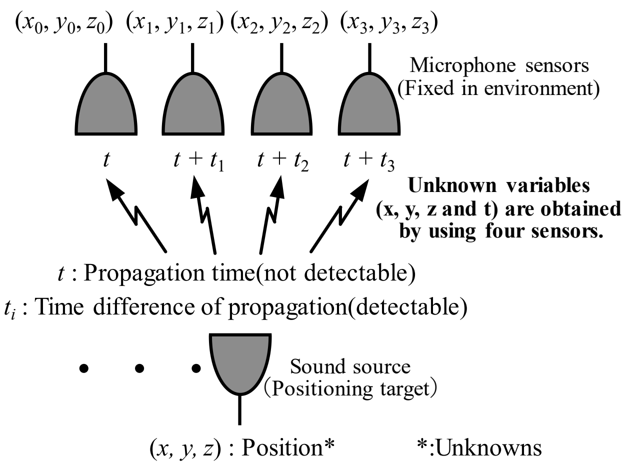


Figure 1. Positioning principle.

only for positioning but also for the transmission of other information, which would appear to add value to the system.

## III. INFORMATION TRANSMISSION BY SOUND USED FOR POSITIONING

### A. *Process of embedding information*

Figure 3 shows the process used to embed data in the sound used for positioning. The elements surrounded by dotted block were added to the system described in [5]. The time of reception can be obtained by correlating the received sound, which is spread by the same M sequence code, with its replica stored in the receiver. The authors propose modulating the sound source with data such as the output of a temperature sensor, etc., as the first modulation before diffusion processing.

The receivers get this spread spectrum signal via a microphone sensor. The correlation calculation is carried out to determine the time of reception, and the obtained values are used for positioning as described in Section II-A. Here, inverse diffusion processing is applied using the same M sequence code from this timing to retrieve the modulated signal. After this demodulation processing, the summation of the demodulated signal is carried out in order to obtain the desired data.

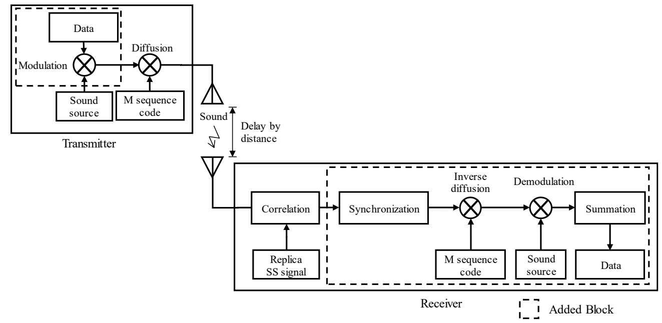


Figure 3. Block diagram for data embedding and transmission.

### B. *Confirmation by numerical simulation*

Before constructing the experimental system, a simulation was carried out to verify the validity of the proposed procedure by using MATLAB programming. A 3rd order M sequence code was used in this simulation for ease in confirming the signal variation.

The simulation result is shown in Figure 4. The graph in the top line represents the data for transmission and that in the bottom is the data retrieved by the proposed procedure. The sound source is modulated based on the data (-1, 1, . . .), here -1, 1 which means 0, 1. This signal is modulated again by the M sequence code (1, 1, 1, -1, 1, -1, -1, . . . : -1 means 0 in the figure) as a second modulation. The received signal is the same as the transmitted signal, although its time of reception indicates the time required for sound propagation. The time of reception was determined by a correlation calculation using the replica, and the inverse diffusion was carried out from this timing. The signal to be demodulated was obtained after these procedures. The resulting data was obtained after summation of the demodulated signals.

It was confirmed that the modulated signal was regenerated on the receiving side after inverse diffusion. The required data is obtained after demodulation, and summation

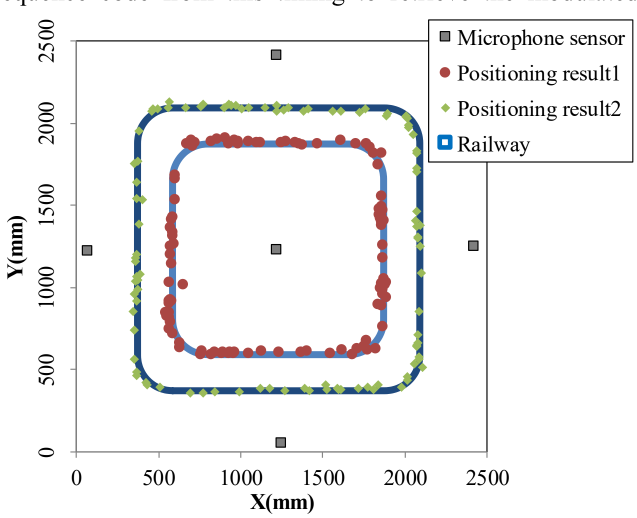


Figure 2. Example of experiment result.

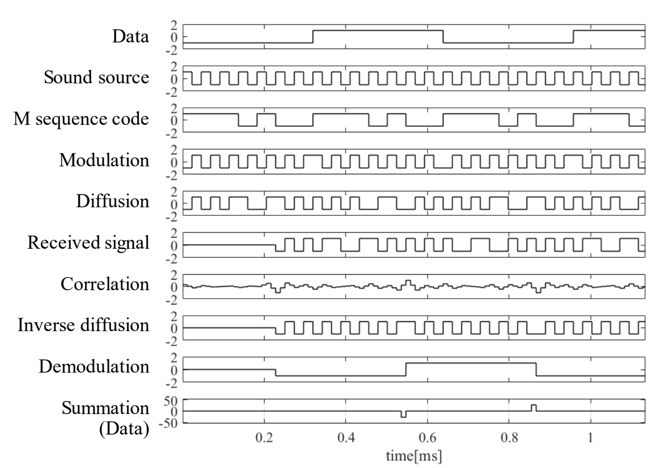


Figure 4. Simulation result for data transmission.

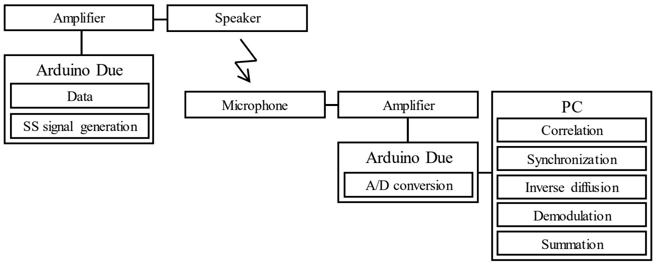


Figure 5. Experimental configuration for data transmission.

with this demodulated signal can enhance the reliability of data transmission, as shown in the graphs in Figure 4.

## IV. EXPERIMENT AND EVALUATION

### A. *Experiment configuration*

The authors have constructed an experimental system to confirm the validity of the proposed method. The experimental configuration is shown in Figure 5. A speaker (DB Products Limited: UM1515IA085008LFMP) connected to an amplifier was used as the sound source. The random 0 (-1), 1 code was used to provide the data, a rectangular wave was selected as the sound source, and this signal was modulated using the data and the M sequence code on an Arduino board (Arduino Due). Here, the data was created by a random data generator in advance and stored in the memory of the Arduino Due. The speaker was connected to this board via the amplifier to transmit the sound signal.

The signal received by a microphone sensor (Primo: EM-158) was amplified in the receiver, and A/D conversion was carried out in the Arduino Due before transmission to the PC. Then the correlation calculation, inverse diffusion, demodulation and summation were conducted to retrieve the original data that was embedded in the transmitted sound. The experimental setup is shown in Figure 6. The experiment was carried out in the laboratory room shown in this photograph and the campus cafeteria at lunch time, which provided a commonly encountered noisy environment.

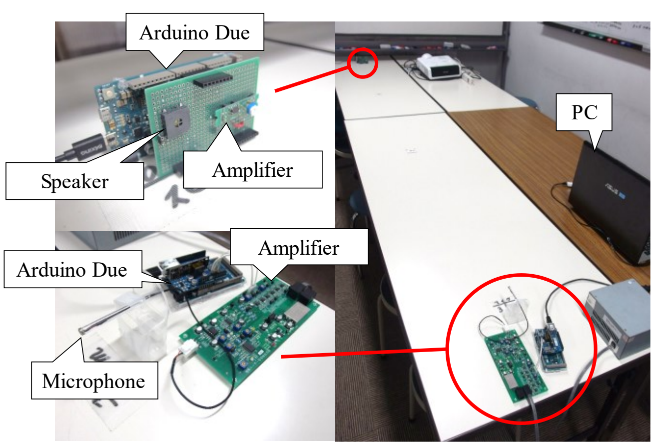


Figure 6. Experimental setup for data transmission.

TABLE I. EXPERIMENTAL PARAMETRES FOR DATA TRANSMISSION

| Item | Unit | Parameters | |
|---|---|---|---|
| Sound source | | Rectangular wave | |
| Source frequency : a | kHz | 22.05 | |
| Sampling frequency of transmission : b | kHz | 44.1 | b = 2a |
| Sampling frequency of reception : c | kHz | 88.2 | c = 2b |
| Data | bit | 1000 | |
| Order of M sequence : d | | 8 | |
| Generator polynomial | | $x^8+x^4+x^3+x^2+1$ | |
| M sequence period : e | chip | 255 | $e = 2^d - 1$ |
| 1 sample length : f | µs | 22.68 | f = 1 / b |
| 1 chip length : g | µs | 45.36 | g = 2f |
| 1 bit time length of data : h | ms | 11.6 | h = ge |
| Transmission rate : i | bps | 86.2 | i = 1 / h |

### B. *Experiment conditions*

The basic experimental parameters are shown in Table I. The chips of M sequence code in one period for diffusion (255 chips) were embedded in 1 bit time length of the original data. The transmission quality was affected by many factors, such as the order of the M sequence code, the distance between the microphone sensor and the speaker, the sound frequency before diffusion, etc. Such factors were verified in this experiment, and also the bit error rate per 1000 information bits and the Signal to Noise Ratio (SNR) were evaluated. The SNR was estimated from the peak value of the correlation calculation and the noise level.

### C. *Experimental results and evaluation*

The experiment was carried out five times under the same conditions to confirm repeatability. Then the average values were evaluated. An example of the correlation calculation result for an 8th order M sequence code is shown in Figure 7. It was verified that the peak appeared clearly, therefore positioning could be performed, and the inverse diffusion could be obtained from this result.

Figure 8 shows the summed results of demodulated signals for the results of 6th order and 8th order M sequence codes, respectively. Since the period of 8th order code is larger than that of 6th order code, the summation values in the 8th order result are larger. The positive values are considered to be 1, and the negative values are -1. It was confirmed that the summation values obtained with 8th order were more stable than those from 6th order. This means that more reliable data transmission can be achieved with an 8th order M sequence code, although its transmission speed (bits per second) is less than that of 6th order. Table II summarizes the experimental results. Nominal parameters for sound and diffusion are shown in Table I. One parameter and the experimental environment were changed to evaluate the effect on transmission performance. The distance between

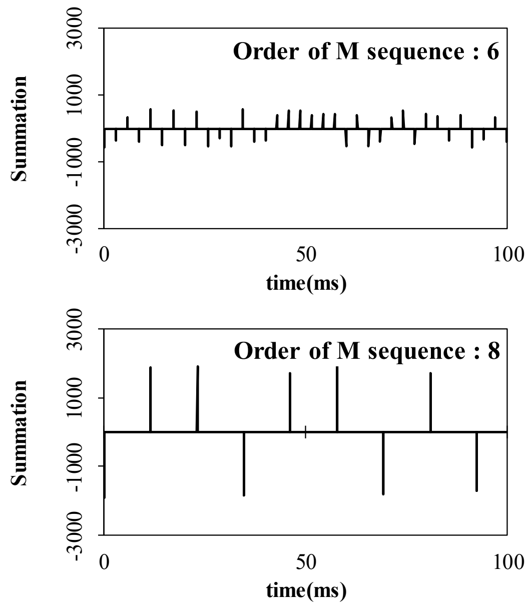


Figure 8. Results of summation after demodulation.

the speaker and the microphone sensor was set at 3 m, a length based on the floor to ceiling distance. The experiment was usually carried out in the laboratory room on campus (environmental noise: 40.4 – 56.2 dB) and the campus cafeteria at lunch time (66.7 – 93.4 dB). The following facts were confirmed in this experiment.

TABLE II. EXPERIMENTAL RESULTS FOR DATA TRANSMISSION

| Parameters | Error bit | | SNR | |
|---|---|---|---|---|
| | *Usual* [a] | *Noisy* [b] | *Usual* [a] | *Noisy* [b] |
| **Order of M Sequence** | | | | |
| 4 | 2 / 1000 | Unmeasurable | 2.2 | 2.2 |
| 6 | 0 / 1000 | 114 / 1000 | 3.7 | 2.8 |
| 8 (Nominal) | 0 / 1000 | 0 / 1000 | 7.2 | 4.8 |
| **Sound frequency before diffusion [kHz]** | | | | |
| 11.025 | 0 / 1000 | 0 / 1000 | 8.9 | 5.4 |
| 22.05 (Nominal) | 0 / 1000 | 0 / 1000 | 7.2 | 4.8 |
| 33.075 | 0 / 1000 | 1 / 1000 | 7.1 | 4.9 |
| **Sound volume [dB]** | | | | |
| 40.0 | 36 / 1000 | N/A [d] | 4.7 | N/A [d] |
| 55.0 | 0 / 1000 | N/A [d] | 6.1 | N/A [d] |
| 72.8 (Nominal) | 0 / 1000 | N/A [d] | 7.2 | N/A [d] |
| **Order of low cut filter for transmitted sound data** [c] | | | | |
| 0 (Nominal) | 0 / 1000 | 3 / 1000 | 5.2 | 3.5 |
| 2 | 0 / 1000 | 11 / 1000 | 4.7 | 3.7 |

a. Environmental noise 40.4~56.2[dB]
b. Environmental noise 66.7~93.4[dB]
c. In this case, order of the M sequence was 7.
d. N/A means sound volume could not be measured due to a noisy environment.

(1) In the case of diffusion by a greater than 6th order M sequence code, quite a high quality of transmission performance can be obtained in a normal noise environment.

(2) Even in quite noisy conditions from 66.7 dB to 93.4 dB, the quality can be maintained if an 8th order M sequence code is used for diffusion. This result indicates that transmission using spread spectrum is robust in a noisy environment. The authors found it feasible to realize both of positioning and data transmission functions by one sound system.

## V. CONCLUSION

The authors proposed a method to embed data in the sound used in a positioning system. The spread spectrum technique is applied to the sound signal, which is modulated based on the data. The feasibility and validity of the proposed method was confirmed by a numerical MATLAB simulation before an experiment was performed.

The experimental system was designed to verify the proposed method and to evaluate transmission quality. The order of the M sequence code for diffusion, the sound frequency and the environmental noise level were varied in the experiments. It was verified that the data can be transmitted along with the diffused sound data in which it is embedded, and high quality can be retained even in a noisy environment.

The final goal is to realize a system that can transmit both positioning information and sensor data. Integrating both functions remains as the next stage of the project.

## ACKNOWLEDGMENT

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# Towards Technology Acceptance Assessment in Ambient Intelligence Environments

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***Abstract*— This paper discusses technology acceptance in the context of Ambient Intelligence (AmI) environments. Determining what would make a technology acceptable by users was widely recognized as a significant field of research since the seventies. Ever since several models have been developed, while recent advances in technology have led to increased research interest in assessing technology acceptance in a variety of domains. This has resulted in a plethora of studies and an extensive number of parameters that can be considered important towards predicting the acceptance of a given technology by its target audience. An important concern is how to practically employ these models for the assessment of AmI environments, given their high complexity and the wide range of potential contexts and target users. To this end, this paper carries out a review of the most important models and their evolution over time, as well as a review of studies extending these models in a variety of domains beyond the workplace. Furthermore, a classification of the parameters studied across these models is carried out, identifying a common feature across existing technology acceptance studies, namely that all assessments are based on self-reported metrics. This highlights the need for a synergistic evaluation approach, where assessment will move beyond self-reported or observed metrics and will be supported and assisted by the AmI environment itself.**

***Keywords-Technology Acceptance; Models classification; Ambient Intelligence;***

## I. INTRODUCTION

Determining what would make a technology acceptable by users was widely recognized as a significant field of research since the seventies, when approaches towards defining factors that seem to influence the use of technology have been proposed. Nevertheless, it was in the mid-eighties when researchers concentrated their efforts on developing and testing models that could help predicting system use [1]. Several theoretical models have been proposed to this end, with roots in information systems, psychology, and sociology [2]. Over time, as new technological advancements occurred, the research interest in technology acceptance moved beyond the workplace (where technology and more specifically computers were initially used) to other domains and contexts of use.

Ambient Intelligence is an emerging field of research and development, constituting a new technological paradigm, moving beyond the Ubiquitous Computing paradigm. The notion of Ambient Intelligence is becoming a de facto key dimension of today's Information Society, spanning across every Human-Computer Interaction (HCI) research and development domain, since next generation digital products and services are explicitly designed in view of an overall intelligent computational environment [3]. Although Ambient Intelligence is a multidisciplinary field, its objective is to offer proper services to users, therefore the implications of user evaluation should be considered in this "service-evaluation-research" loop [4].

As AmI environments are equipped with various sensors and monitoring capabilities, privacy and trust become issues of paramount importance for their inhabitants [5], while technology acceptance needs to be studied from a new perspective. Ambient Intelligence may be found in any potential daily living environment, such as the home, the workplace, health care, educational setting, or public spaces [6], embracing any activity carried out in these environments. Therefore, the parameters that may impact user acceptance of an Ambient Intelligence environment definitely extend beyond the parameters suggested in the first models studying computer acceptance in workplace environments. As a first step towards studying acceptance in AmI environments, this paper carries out a short review of the initial technology acceptance models and their evolution, as well as their adaptations to address different contexts of use. Furthermore, a classification of the parameters studied in these models is provided, with the aim to assist researchers in identifying parameters that should be included in studying user acceptance of AmI environments, according to the target environment and context of use.

The purpose of this paper is not to carry out a detailed literature review; instead, it focuses on identifying parameters that have been suggested to influence technology adoption in various contexts. Therefore, the main criteria for including a paper in this review were: (i) the paper should propose a specific model directly relevant with technology acceptance, and (ii) at least one novel variable should be contributed by the model. The main focus of this work is on proposing a classification of the parameters explored in such models and - through this - highlight the potential of moving from self-rated experiences towards technology-assisted assessment of user experience in Ambient Intelligence environments.

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The paper is structured as follows: Section 2 introduces the most significant technology acceptance and adoption models, while Section 3 presents models for technology acceptance beyond the organizational context, organized in categories. Section 4 provides a classification of the parameters examined in the presented models. Section 5 concludes the paper by discussing directions towards technology acceptance assessment in AmI environments.

## II. Technology Acceptance

One of the most influential models, the Technology Acceptance Model (TAM), has been proposed by Davis [7] and defines two components that affect a user's attitude towards using a technology, namely: (i) perceived usefulness, described as the degree to which an individual believes that using a particular system would enhance their job performance and (ii) perceived ease of use, defined as the degree to which an individual believes that using a particular system would be free of physical and mental effort. Extending the initial TAM model and taking into account theoretical constructs spanning from social influence processes to cognitive instrumental processes, Venkatesh and Davis introduced the TAM2 model [8], which added seven components to the initial TAM model, and namely:

- Subjective norm: a person's perception that most people who are important to him think he should or should not perform the behavior in question.
- Voluntariness: the extent to which potential adopters perceive the adoption decision to be non-mandatory.
- Image: the degree to which use of an innovation is perceived to enhance one's status in one's social system.
- Experience: the experience gained while using a given technology over time.
- Job relevance: an individual's perception regarding the degree to which the target system is applicable to his or her job.
- Output quality: how well the system performs tasks.
- Result demonstrability: the tangibility of the results using the innovation.

TAM has been widely adopted and studied by the research community, resulting in a considerable number of external variables that have been introduced as factors influencing how users perceive the usefulness and ease of use of a technology, while reviews of TAM have constituted the objective of several meta-studies [9]-[11]. Variables extending the initial TAM model include [9]:

- Relative advantage: the degree to which an innovation is perceived as being better than its precursor.
- Compatibility: the degree to which an innovation is perceived as being consistent with the existing values, needs, and past experiences of potential adopters.
- Trialability: the degree to which an innovation may be experimented with before adoption.
- Self-efficacy: an individual's convictions about his or her abilities to mobilize motivation, cognitive resources and courses of action needed to successfully execute a specific task within a given context.
- End user support: specialized instruction, guidance, coaching and consulting.
- Objective usability: the actual level of system effect on the completion of specific tasks.
- Personal innovativeness: the individual's willingness to try out any new technology.
- Cognitive playfulness: the individual's cognitive spontaneity when using a technology.
- Social presence: the degree to which a medium permits users to experience others as being psychologically present.
- Visibility: the degree to which the innovation is visible in the organization.
- Computer attitude: the degree to which a person likes or dislikes the object.
- Accessibility: physical and information accessibility.
- Management support: the degree of support from managers to ensure sufficient allocation of resources.
- Computer anxiety: an individual's apprehension, or even fear, when she/he is faced with the possibility of using computers.
- Perceived enjoyment: the extent to which the activity of using a specific system is perceived to be enjoyable in its own right, aside from any performance consequences resulting from system usage.
- Facilitating conditions: resource factors (such as time and money) and technology compatibility issues that may constrain usage.

Addressing the need for defining the determinants of perceived ease of use, TAM3 was proposed [12] by extending TAM 2 to include the following determinants: computer self-efficacy, perception of external control, computer anxiety, computer playfulness, perceived enjoyment and objective usability.

Following a different approach, Thompson, Higgins, and Howell [13] utilized a subset of the theory of human behavior [14] to create a model of personal computer utilization. Applying this theory implied that the utilization of a Personal Computer (PC) by a knowledge worker in an optional use environment would be influenced by the individual's feelings toward using PCs, social norms in the work place concerning PC use, habits associated with computer usage, the individual's expected consequences of using a PC, and facilitating conditions in the environment conducive to PC use.

A significant theoretical framework in the area of technology diffusion and adoption was proposed by Rogers [15] and described the innovation-diffusion process as an uncertainty reduction process. Five attributes of innovation were proposed, which are important for technology adoption: relative advantage, compatibility, complexity, trialability, and observability. Other variables determining the rate of adoption of innovations are: the type of innovation decision (optional, collective, authority), the communication channels used to diffuse an innovation, the nature of the social systems (its norms and the degree to which the communication network structure is highly interconnected), as well as the promotion efforts of change agents. Moore and Benbasat [16] also adopted the Innovation Diffusion Theory (IDT), and further extended it with two constructs, namely image and voluntariness of use. Tornatzky and Klein [17] carried out a review and meta-analysis of seventy-five articles concerned with innovation characteristics and their relationship to innovation adoption and implementation, and extracted ten characteristics as the most important and frequent ones, five of which are the attributes of innovation of IDT. The additional five innovation characteristics are:

- Cost: the cost of an innovation is assumed to be negatively related to the adoption and implementation of the innovation; the less expensive the innovation, the more likely it will be quickly adopted and implemented.
- Communicability: the degree to which aspects of an innovation may be conveyed to others.
- Divisibility: the extent to which an innovation can be tried on a small scale prior to adoption, which is closely related to trialability.
- Profitability: the level of profit to be gained from adoption of the innovation.
- Social approval: refers to status gained in one's reference group, a nonfinancial aspect of reward as a function of adopting a particular innovation.

With the aim to facilitate researchers confronted with a choice among a multitude of models, Venkatesh et al. [18] proposed the Unified Theory of Acceptance and Use of Technology (UTAUT). According to this theory, four constructs are direct determinants of user acceptance and user behavior: performance expectancy, effort expectancy, social influence and facilitating conditions. In addition, four moderators have been identified for the aforementioned determinants, namely gender, age, experience, and voluntariness of use. An extension to the UTAUT model, named UTAUT2, has been proposed by Venkatesh, Thong, & Xu [19] to study acceptance and use of technology in a consumer context and incorporates three additional constructs:

- Hedonic motivation: the fun or pleasure derived from using a technology.
- Price value: the consumers' cognitive trade-off between the perceived benefits of the applications and the monetary cost for using them.
- Habit: the extent to which people tend to automatically perform learnt behaviors.

## III. Technology Acceptance Beyond The Workplace

The majority of the aforementioned fundamental models have initially been applied in organizational settings and examined technology adoption in the workplace context, since when they were initially created, computers were not used in the home or other environments, while technology mostly referred to PC usage. Recent advances in technology have led however to increased research interest in assessing technology acceptance in a variety of domains. This section reports on efforts utilizing or extending the aforementioned models by adding new variables, towards assessing other contexts or technologies, focusing on the most prevalent contexts, as well as contexts relevant to AmI (e.g., ubiquitous computing, Ambient Assisted Living).

### *A. Technology Adoption in Households*

As a result of studying technology adoption in households, Brown and Venkatesh [20] introduced the Model of Adoption of Technology in Households (MATH), which includes the following constructs:

- Utilitarian outcomes, which can be divided into beliefs related to personal use, children, and work.
- Hedonic outcomes, defined as the pleasure derived from the consumption, or use, of a product.
- Social outcomes, which are described as the "public" recognition that would be achieved as a result of adopting an innovation.
- Social influence that is the extent to which members of a social network influence one another's behavior, and can be further classified into friends and family influences, secondary sources influences, as well as workplace referents' influences.
- External constraints, which are characteristics of the PC and its environment and include the rapid change in technology and/or fear of obsolescence, declining cost, and cost.
- Internal constraints, reflecting perceptions of the individual's relationship with technology and include the perceived ease of use and requisite knowledge.

Furthermore, the model defines the following moderators, which are related to household life: marital status, age, child's age and income.

### *B. World Wide Web (WWW)*

Moon and Kim [21] extended and empirically validated TAM for the WWW context. The results of their study indicate that perceived usefulness, perceived ease of use and perceived playfulness are important determinants of users' perceptions towards using the WWW, but also that playfulness and perceived ease of use (intrinsic motivations) had a more powerful impact than perceived usefulness (extrinsic motivation) in the case of the WWW. The effect of Internet experience and website experience has also been studied, highlighting the positive impact of experience [22]. More specifically, it was found that in users with high experience, (a) the influence of perceived usefulness on the process of forming the attitude to the website is substantially greater than in users with low experience, while (b) the influence of perceived ease of use on the attitude towards the website is substantially smaller than in users with low experience.

### *C. Gaming and Virtual Worlds*

In the domain of WWW and especially with regard to online games, TAM was extended with the constructs of

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social norms, critical mass and flow experience [23], concluding that social norms and flow affect users' intention to play an online game, while critical mass affects users' attitude towards playing an online game, but not intention directly. Perceived connectedness and perceived mobility were constructs introduced in the domain of mobile social network games [24]. Focusing on serious games, Yusoff, Crowder, and Gilbert extended TAM with the concepts of transfer of learnt skills, learner control, reward, as well as situated and authentic learning [25]. In the context of virtual worlds, the application of TAM highlighted that communication, collaboration, and cooperation are central in influencing behavioral intention to use and acceptance of the virtual world [26].

### D. Trading, Shopping and Internet banking

The moderating effect of perceived trust has been explored as an extension of TAM in the context of online trading systems [27]. Testing the model supported that trust is an important antecedent of user acceptance in this context, and that perceived security affects user's trust. Trust and perceived risk have also been added as extensions to TAM with regard to e-commerce in order to study the user's intention to transact [28], [29]. Studies that have been carried out to test the extended TAM [28] indicated that trust is positively associated with intention to transact, perceived usefulness and perceived ease of use, and negatively associated with perceived risk. Furthermore, reputation was a significant antecedent of intention to transact, and along with satisfaction with past transactions and web shopping frequency, they were significant antecedents of trust. The concept of consumer trust has been extensively studied and further decomposed in the antecedents of personality-based, cognition-based, knowledge-based, calculative-based and institution-based trust [30].

Previous experience with the Internet was found to be of significant importance for both initial and repeated purchases, while users who consider that they have more competence and capacity also have better perceptions about e-commerce and, as a consequence, carry out more online purchases [31]. E-shopping quality is another factor that was found to be influential in perceptions of usefulness, trust, and enjoyment, which in turn influence consumers' attitudes toward e-shopping [32]. In this study, e-shopping quality consists of four dimensions, namely web site design, customer service, privacy / security and atmospheric / experiential quality.

The role of perceived risk, as well as that of perceived benefit, have been included in a TAM extension studying user acceptance of internet banking [33]. In more details, the results of the study confirmed that perceived benefit has a primary effect on intention to use online banking, as well as that security, financial, time, social, and performance risks all emerged as negative factors in the intention to adopt online banking. Risks have been further explored and analyzed as a parameter for e-services adoption by Featherman and Pavlou [34], comprising the facets of performance, financial, time, psychological, social, privacy and overall risk.

### E. eLearning and mLearning

In the context of eLearning, the TAM model has been expanded to include system characteristics, and more specifically: (i) functionality, which refers to the perceived ability of a eLearning system to provide flexible access to instructional and assessment media, (ii) interactivity, which refers to interaction support between teachers and students, and students themselves, and (iii) response time [35]. The model also included the user attributes of self-efficacy and internet experience, and studied the impact of the aforementioned factors on perceived usefulness and perceived ease of use, as well as the use of the system for supplementary learning and for distance education. Saadé and Bahli [36] extended TAM, taking into account the moderating effect of cognitive absorption, which in turn is defined by the user's temporal dissociation, focused immersion and heightened enjoyment when using the online learning system. The role of cognitive absorption, as well as system attributes has been pointed out in a TAM extension based on the expectancy disconfirmation theory [37]. The results of the study suggest that continuance intention is determined by satisfaction, which in turn is jointly determined by perceived usefulness, information quality, confirmation, service quality, system quality, perceived ease of use and cognitive absorption.

eLearning self-efficacy, followed by subjective norm, have been emphasized as the most important constructs explaining eLearning technology adoption by university students [38]. The role of eLearning experience on continuance intention has also been explored by Lin [39], highlighting that (i) negative critical incidents and attitude are the main determinants of the users' intention to continue using the e-learning, irrespective of their level of e-learning experience, (ii) the impact of negative critical incidents on perceived ease of use is greater for less experienced users, while the impact of negative critical incidents on perceived usefulness is greater for more experienced users; and (iii) perceived ease of use has a more critical effect on the attitude and continuance intention of less experienced users, whereas perceived usefulness is found to be a stronger determinant of the attitude and behavioral intention of more experienced users. The importance of digital literacy in eLearning use for professional development has been stressed in a study extending the UTAUT model [40], which found that digital literacy has an impact on users' performance and effort expectations that in turn affect continuance intention and eventually performance. The adoption of IT by educators has also constituted the subject of several studies, highlighting that digital competencies and institutional support have an important role in adoption intentions [41].

On the other hand, in terms of mLearning adoption intention, near-term usefulness, long-term usefulness and personal innovativeness have proved to have significant influence, with the most important predictor being long-term usefulness [42]. Mobile technology adoption by educators has been claimed to be influenced, among others, by mobile device anxiety, as well as resistance to change, defined as the difficulty to break with routines and the emotional stress generated [43].

eLearning is a domain in which many studies have been carried out in terms of user acceptance. A meta-analysis of eLearning technology acceptance studies [44] identified that TAM is indeed the most-used acceptance theory in the specific context, but more importantly that the size of the causal effects between individual TAM-related factors depends on the type of e-learning technology.

### *F. Mobile Technology*

Advances in mobile technology have led to increased interest in exploring adoption intentions and acceptance of services in this domain. Lu, Yao, & Yu [45] modified TAM to explore adoption of wireless internet services via mobile technology, and found strong causal relationships between social influences, personal innovativeness and the perceptual beliefs—usefulness and ease of use, which in turn impact adoption intentions. A model has been proposed by Nysveen, Pedersen, & Thorbjørnsen [46], integrating the motives that are revealed in information systems theories, uses and gratification theory, and domestication theory and examining four mobile services, namely text messaging, contact, payment, and gaming. The model includes the motivational influences of usefulness, ease of use, enjoyment, and expressiveness, attitude towards using the mobile services, normative pressure as a social influence, and behavioral control reflecting resource-related influences such as the user's economy, experience and skills in using a service. The results indicate that attitude towards using the service is moderated by enjoyment, usefulness, and ease of use, while users' intention to use the service is moderated by attitude towards the service, expressiveness, enjoyment, usefulness, ease of use, normative pressure and behavioral control. Taking into account TAM, as well as other models extending it for e-commerce acceptance, Fang, Chan, Brzezinski, & Xu [47] propose a new model focusing on mobile commerce identifying the moderating effects of task type on technology acceptance. A study was carried out to test the proposed model, and the results highlight that perceived usefulness and perceived ease of use were important to user intention to perform general tasks that do not involve transactions and gaming on wireless handheld devices, while perceptions of playfulness influence user intention to play games using wireless technology, and user intention to transact on handheld devices is affected by perceived usefulness and perceived security.

The role of context in the user acceptance of mobile systems was highlighted and studied for mobile ticketing systems [48]. The results of the study indicated that the context of use has an important effect on intention to use the mobile service, as well as a mediating effect of perceived usability on user intention, while other decision factors, such as ease of use and compatibility, had a direct effect. Considering the mobility context, Zarmpou, Saprikis, Markos, and Vlachopoulou [49] extended TAM and introduced the concept of relationship drivers as those dimensions that create a relationship between the consumers and the m-services, including for instance the time and location personalization of m-services, their adaptation to the consumers' profile, the consumers' dynamic permission option and the consumers' reward by the use of the m-services. Testing the model highlighted that relationship drivers have an important effect on perceived usefulness and behavioral intention.

### *G. Health Technology*

Although the success of health Information Technology (IT) certainly goes beyond user acceptance, where users may be health professionals or patients, increasing interest in this application domain has raised the importance of theories that predict and explain health IT acceptance and use [50]. Such theories are based on existing models, such as TAM, while findings of reviews and meta-studies highlight that TAM predicts a substantial portion of user acceptance of health IT, however several additions and modifications have been proposed [50].

An alternative approach to extending TAM aimed at identifying barriers to health IT adoption, instead of extending it with determinants positively influencing acceptance [51]. To this end, the following barriers have been identified: interruption of traditional practice patterns, lack of evidence regarding the benefits of IT, organizational issues, as well as system-specific issues, such as reliability and dependency. An extended TAM model for health IT acceptance suggested information quality and enabling factors as second order constructs that affect perceived usefulness and perceived ease of use [52]. In the proposed model, information quality is posited to be determined by accuracy, content, format and timeliness, while computing support and self-efficacy constitute enabling factors. The results of a study carried out to test the model highlight that the quality of the information provided by the system and the extent to which the user feels they have the technical support or skills to make use of the system are both significant. With a focus on attributes of the individual that have an impact on health IT acceptance, IT feature demands and IT knowledge have been proposed as additional TAM constructs, while the physician's specialty has been studied as a moderator [53]. The individual's technological attitude has also been explored with regard to technology acceptance in a study focusing on mobile electronic medical record adoption by nurses [54], emphasizing the importance of optimism on perceived usefulness and the impact of optimism, innovativeness, insecurity and discomfort on perceived ease of use.

### *H. Assistive Technology and Ubiquitous Computing*

Assistive Technology (AT) and robotics is another technological advancement that has led to further exploration of technology acceptance. The Almere model, an extension of the UTAUT model [55], considers the effect of perceived enjoyment, social presence, perceived sociability, trust, and perceived adaptivity. Perceived adaptivity refers to the capability of the system to change over time in order to support the changing conditions and needs of its users. Testing the model identified among others that perceived adaptivity directly affects user attitude and perceived usefulness, perceived sociability affects perceived enjoyment and social presence, while intention to use is directly influenced by social influences, attitude, perceived usefulness and ease of use, as well as perceived enjoyment.

The Ubiquitous Computing Acceptance Model [56] has been proposed to predict whether potential users will accept Ubiquitous Computing (UbiComp), by studying the relationships among trust, security, privacy, usefulness, ease of use and intention to use a ubiquitous computing technology. In the UbiComp domain, the Pervasive Technology Acceptance Model (PTAM) [57] has extended TAM by adding the constructs of trust and integration as direct determinants of behavioral intention, while it adds usage motivation, socioeconomic status, age, gender, and expertise as moderators. Trust is examined in terms of keeping the information collected about the individual as confidential and in terms of trusting the application to behave as expected, given its potential to tailor its behavior. Integration refers to how well the technology is integrated into the individual's life (e.g., by not distracting them or interfering with their other activities).

## IV. TECHNOLOGY ACCEPTANCE AND AMBIENT INTELLIGENCE

In summary, research in the direction of technology acceptance has led to the aggregation of a considerable number of parameters that can be considered as important towards predicting the acceptance of a given technology by its target audience. It should be noted that the literature review that has been carried out was not exhaustive, as there are more studies for the aforementioned domains and also there are studies on technology acceptance for other domains that have not been included in this paper. Literature abounds with studies of users' acceptance in wide a variety of domains, such as e-logistics [58], online tax system [59], hotel office front systems [60], Enterprise Resource Planning (ERP) systems [61], electronic mediated commerce using interactive television [62], Radio-frequency Identification (RFID) technology [63], Internet of Things [64], etc.

Instead, the purpose of the current review was to emphasize the plethora of parameters that should be taken into account, especially in the context of AmI environments, due to their technological complexity and diversity in context of use. As a result, the review has included studies mostly relevant to AmI and studies of major everyday life domains, with a focus on those that have introduced new constructs in acceptance models. Indeed, the presented review and classification has resulted in 73 parameters of technology acceptance that act as direct determinants, antecedents or moderators of technology acceptance. Also, it is noteworthy that the overwhelming majority of these parameters (98.92%) is assessed in the various studies through questionnaires, asking users to self-report their characteristics, attitudes and perceptions.

An important concern is how to practically employ these models in the context of the assessment of Ambient Intelligence technologies. To this end, a classification of the aforementioned parameters is required. Attributes that can be used for this classification include:

- Category of reference: if the metric is used to describe an attribute of the individual, of the social environment or the system under evaluation
- Assessment method: which method will be employed to find out the value of the specific metric (e.g., questionnaire, observation, automated system measurement)
- The context in which the specific metric can be applied (e.g., workplace, education, health, home environment, public environments)

Based on this suggestion, the tables below list all the metrics identified in literature, as follows: Table I lists all system-related parameters,

Table II encompasses attributes describing social influences, as well as environment factors, while

Table III features parameters describing system impact on the individual, and

Table IV refers to parameters concerning the individual (user). Each table includes four columns: (i) the parameter evaluated, and its various synonyms met across literature, (ii) the assessment method, (iii) the context, and (iv) references to publications that include the specific parameter in the proposed models. In summary, as shown in Figure 1, more than half of the parameters refer to system attributes.

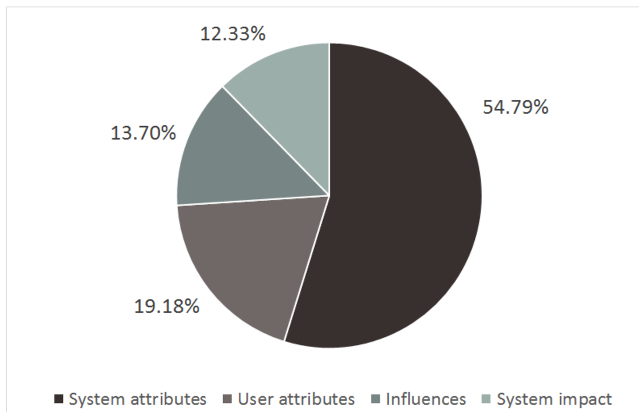


Figure 1 Parameters per category of reference

## V. CONCLUSION

Technology acceptance, in terms of prediction and estimation, has been in the focus of research since the seventies. Although technology and its context has largely evolved ever since from a typical computer in the workplace to hidden microcomputers in everyday appliances, technology acceptance remains important and an active research topic. In the light of the new advancements expected in AmI environments, which address a broad range of technologies, users, and contexts, this paper has reviewed technology acceptance models as they have evolved to address a wide range of technologies and contexts of use. Furthermore, a classification has been carried out of the factors that have been found to directly or indirectly impact technology acceptance, organizing them in system-related, individual-related, social and environmental influence, as well as system impact factors. The literature review and the classification have highlighted that all factors have been assessed in previous approaches through questionnaires, as self-reported metrics.

Although the self-reporting approach is inevitable in many cases, and the only possible method when the first studies were carried out, this is no longer an ideal solution in the context of AmI environments. On the one hand, the number of questions to be asked to the user may become unmanageable in such environments, if all the relevant aspects are to be assessed. On the other hand, an AmI environment has the capability to provide measurements through its sensors that will constrain the number of questions that need to be asked to the user. The vision of AmI can bring about new perspectives to technology acceptance and evaluation, facilitating not only the environment in adapting itself to better serve the needs of the user, but also evaluators aiming to assess the overall user acceptance of such environments. This potential highlights the need for a user acceptance evaluation model in AmI environments, aiming to assess a wide range of characteristics and qualities of such environments, taking into account traditional and modern models and evaluation approaches.

TABLE I. PARAMETERS REFERRING TO THE SYSTEM

| Parameter | Method | Context | Ref. |
|---|---|---|---|
| Perceived usefulness | Quest. | Organizational | [7], [8] |
| Perceived ease of use | Quest. | Organizational | [7], [8] |
| Output quality | Quest. | Organizational, eLearning, Health IT | [8], [37], [52] |
| Result demonstrability | Quest. | Organizational | [8] |
| Relative advantage | Quest. | Organizational | [9], [16] |
| Compatibility | Quest. | Organizational, Mobile services | [9], [16], [48] |
| Trialability / Divisibility | Quest. | Organizational | [9], [16] |
| End-user support | Quest. | Organizational | [9] |
| Objective usability | Quest. | Computer software | [9], [12] |
| Social presence | Quest. | Organizational, AT | [9], [55] |
| Accessibility | Quest. | Organizational | [9] |
| Perceived enjoyment | Quest. | Organizational, Mobile services, AT | [9], [12], [46],[55] |
| Complexity | Quest. | Organizational | [16] |
| Cost | Data analysis | Organizational | [17] |
| Price Value | Quest. | Mobile Internet | [19] |
| External constraints (PC & environment characteristics) | Quest. | Household | [20] |
| Transfer of learnt skills | Quest. | Serious games | [24] |
| Learner control | Quest. | Serious games | [24] |
| Reward | Quest. | Serious games | [24] |
| Collaboration / Cooperation, Connectedness | Quest. | Virtual worlds, Mobile social network games | [26], [24] |
| Mobility | Quest. | Mobile social network games | [24] |
| Perceived security | Quest. | Online Trading, UbiComp | [27], [56] |
| Reputation | Quest. | E-commerce | [28] |
| Perceived risk* <br>* security, financial, time, social risk (internet banking) <br>* performance, financial, time, psychological, social, privacy and overall risk (e-services adoption) | Quest. | E-commerce Internet banking | [28], [33], [34] |
| Web site design | Quest. | E-commerce | [32] |
| Customer service | Quest. | E-commerce | [32] |
| Atmospheric / experiential quality | Quest. | E-commerce | [32] |
| Perceived benefit | Quest. | Internet banking | [33] |
| Functionality | Quest. | Moblie sevices eLearning | [35], [49] |
| Interactivity (between teachers & students, and students themselves) | Quest. | eLearning | [35] |
| Response time | Quest. | eLearning | [35] |
| Expressiveness | Quest. | Mobile services | [46] |
| Perceived adaptivity | Quest. | Mobile services, AT, UbiComp | [49], [55], [57] |
| Reliability | Quest. | Health IT | [51] |
| Accuracy | Quest. | Health IT | [52] |
| Timeliness | Quest. | Health IT | [52] |
| Personalization | Quest. | Mobile services | [49] |
| Perceived sociability | Quest. | AT | [55] |
| Privacy | Quest. | UbiComp | [56], [57] |
| Integration | Quest. | UbiComp | [57] |

TABLE II. PARAMETERS REFERRING TO SOCIAL INFLUENCES AND INFLUENCE OF THE ENVIRONMENT

| Parameter | Method | Context | Ref. |
|---|---|---|---|
| Social factors / Subjective norm / Normative influences / Normative pressure / Social influence / Social norm | Quest. | Organizational, Household, Online games, Mobile services | [8], [13], [18], [20], [23] [45], [46] |
| Voluntariness | Quest. | Organizational | [8], [16] |
| Image, Social approval, Social outcomes | Quest. | Organizational, Household | [8], [16], [20] |
| Job relevance, Job fit | Quest. | Organizational | [8] |
| Observability, Result demonstrability, Communicability | Quest. | Organizational | [8] |
| Visibility | Quest. | Organizational | [9] |
| Management support, Institutional support | Quest. | Organizational setting, eLearning | [9], [41] |
| Facilitating conditions, Perceptions of external control | Quest. | Organizational | [9], [12], [13], [18] |
| Critical mass | Quest. | Online games | [23] |
| Context of use | Quest. | Mobile services | [48] |

TABLE III. SYSTEM IMPACT

| Parameter | Method | Context | Ref. |
|---|---|---|---|
| Visibility | Quest. | Organizational | [9] |
| Outcome expectations (performance & personal) | Quest. | Organizational | [13], [18] |
| Utilitarian outcomes | Quest. | Household | [20] |
| Flow experience | Quest. | Online games | [23] |
| Cognitive absorption | Quest. | eLearning | [36] |
| Near-term usefuleness | Quest. | mLearning | [42] |
| Long-term consequences of use, Long-term usefulness | Quest. | mLearning | [42] |
| Interruption of traditional practice | Quest. | Health IT | [51] |
| Resistance to change | Quest. | mLearning | [43] |

TABLE IV. PARAMETERS REFERRING TO THE INDIVIDUAL

| Parameter | Method | Context | Ref. |
|---|---|---|---|
| Experience / Self-efficacy / Digital literacy / IT knowledge | Quest. | Organizational, WWW, E-commerce, e-Learning, Health IT, UbiComp | [8], [9], [12], [22], [31], [36], [38], [39], [40], [41], [46], [52], [53], [57] |
| Personal innovativeness | Quest. | Organizational, Mobile services, Health IT | [9], [45], [54] |
| Cognitive playfulness | Quest. | Organizational, WWW | [9], [12], [21] |
| Affect / Computer attitude / Computer anxiety / Technology anxiety / Anxiety towards the system | Quest. | Organizational, mLearning, Houshold | [9], [12], [13] , [20], [43] |
| Habit | Quest. | Organizational, Mobile Internet | [13], [19] |
| Effort expectancy | Quest. | Organizational | [18] |
| Age | Quest. | Organizational, UbiComp | [18], [19], [57] |
| Gender | Quest. | Organizational, UbiComp | [18], [19], [57] |
| Hedonic motivation / Hedonic outcomes | Quest. | Mobile Internet, Household | [19], [20] |
| Edudcation | Quest. | Household | [19] |
| Marital status, Child's age | Quest. | Household | [19] |
| Trust | Quest. | Online Trading, Ecommerce, AT, UbiComp | [27], [28], [30], [55], [56] |
| Income, Socioeconomic status | Quest. | Mobile services, UbiComp | [46], [57] |
| Optimism | Quest. | Health IT | [54] |

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