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CORETA 2021

Forward

Advances on Core Technologies and Applications - Building with and around AI, ML, IoT, 5G, Mobility and Cognition (CORETA 2021), held between November 14 and November 18, 2021, initiated a series of international events covering challenges to make use and correlate results in different scientific and technological achievements.

A plethora of intertwined technologies and applications raised during the last years because of the maturity of core approaches related to Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL), and Cognitive Computing (CC) domains. In parallel, new technologies like 5G, tactile Internet, spatial and terrestrial communications augmented the speed and computing possibilities of networking systems.

Citizen-centric services as well as innovations in transportation, healthcare, industry, and economy, in general become provocative challenges due to the complexity, diversity and the increasing needs of our society. In the virtual eco-systems, where robots are part of society as well, robots-driven industry, robots-citizen care, behavior analytics, affective computing, and empathy set the search for practical applications of deep-learning and knowledge discovery.

While progress is visible, sensitive aspects related to privacy, digital forgery, assisted-living, and semantic processing of the enormous amount of information collected for IoT and wearable devices are still partially solved. Apart intrinsic citizen-focused issues, new self-driven systems and parts (drones, vehicular systems), sustainable and green energy, protection of critical systems, and smart cities challenges ask for innovative correlation and real-time solutions based on the core technologies and applications mentioned above.

We take here the opportunity to warmly thank all the members of the CORETA 2021 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 who dedicated much of their time and effort to contribute to CORETA 2021. We truly believe that, thanks to all these efforts, the final conference program consisted of top-quality contributions. We also thank the members of the CORETA 2021 organizing committee for their help in handling the logistics of this event.

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Phobia Treatment: Virtual Reality Approach

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***Abstract*—A phobia is an overwhelming and exaggerated fear of an object, animal, place, situation, or feeling. Often, people with phobias ignore their symptoms and do not get psychotherapy treatment, either because of the social perspective about people who visit psychologists or simply because they cannot afford the cost of psychotherapy. This research paper proposes a mobile application named FaceYourFear (FyF) integrating Virtual Reality (VR) to help any user to live a cybernetic experience (where the outcomes of a session level can help the patient to move to the next level of treatment), overcome the illness, know about phobia symptoms and get extra information on types of phobias.**

Keywords- Phobia; Technology; Virtual Reality; Android app; Face Your Fear (FyF).

I. Introduction

Phobia comes from the Greek word Phobos and it is defined as an “exaggerated usually inexplicable and illogical huge fear of a particular object” [1] like cats, insects or crowded places. It is a type of anxiety disorder that can affect people’s daily life and, in some cases, it can lead to depression. Phobias are part of anxiety mental disorders and cause intense fear of specific objects, situations or some types of activities [2]. Having phobia is much more serious than a normal logical fear, that is, a specific part of the brain has been found to be responsible for some kinds of phobias [3]. Phobias are categorized as specific (simple), social or agoraphobia (complex). Social phobia regards the fear of participating in certain activities in public like eating or speaking. People suffering from social phobia tend to avoid any social events such as weddings or parties, which affects their social lives and increases their chance to develop depression due to their isolated lifestyle.

VR is a computer-generated simulation where people experience the present. It has been developed with the aim to allow users to handle data with ease by offering an active and dynamic way to perceive and experience fake data. VR is quite intuitive, interactive and it is quick in replying to the user’s requests [4]. It has gained a great interest in its application in several fields, including the automotive industry, entertainment, healthcare, architecture, education and military training.

The extent of VR immersion identifies how much a user is involved with the environment. It can also be regarded as how powerful the user attention is focused on the current task or situation. The immersion presence in the context of VR is the perception of being physically present in a non-physical world. It is commonly based on several parameters such as interaction level, image quality, stereoscopic view and the rate update of the display. VR systems can be classified as (a) non-immersive systems, with limited implementation of VR techniques, (b) semi- immersive systems, with high quality graphics in association with large displays and (c) fully immersive systems, which provide the most effective and real virtual experience to users, but require the usage of a head-mounted display [5].

Smartphones are becoming an integral part of our lives. They possess high computing capabilities, are equipped with a variety of sensors, Internet connectivity, high resolution and touch screen, which have led to the development of a tremendous number of smartphone applications in several areas. Recently, VR glasses have been designed for smartphones, where the phone’s display is viewed as VR content.

Museums offer technological and digital options to enrich the user experience in a visit. However, questions arise like which exhibition/museum could I visit? How to tour it and get the best experience? A hybrid approach to make recommendations for museum visits is proposed by [6], including Internet of Things architecture of beacons, data mining and machine learning. The result is a customized tour with augmented reality that contains a set of recommendations on how to visit a set of museums and obtain a better experience of the visit; the prototype is available in Google Play and it is named “Historic Center”.

The research on VR in education is still in an early stage. Khan et al. [7] measured the impact of VR mobile apps on the learning motivation of undergraduate health science students at the University of Cape Town, South Africa. According to the authors, the Attention, Relevance, Confidence and Satisfaction (ARCS) model guided the understanding of the impact of VR on student motivation where differences in student learning motivation before and after using VR apps were conducted (78 participants). Their results showed that using VR apps increased the learning motivation of students in all ARCS dimensions.

Taking full advantage of this current technology, the present research proposes a system that integrates the smartphone and the VR technologies for phobia treatment.

The rest of the paper is organized as follows. Section II discusses related work while Section III presents the proposed FaceYourFear (FyF) App in terms of architecture and features. Finally, Section IV concludes this paper with future perspectives.

II. STATE OF THE ART

Previsl [8] is a Spanish company that develops and sells VR software. It offers VR Environments for airplanes, elevators (closed spaces and height phobia) and thunderstorms in 13 countries. It provides preparatory flight travel VR scenes such as packing of traveling bags, sitting in terminal and announcements of flights to make the person more comfortable with the environment and anticipate and prepare him/her for the upcoming event. It offers a computer-based VR therapy which is expensive.

CleVR [9] was established in 2010 in the Netherlands with the aim to offer VR environments for various domains. They provide software for VR Exposure Therapy (VRET) in association with Delft University of Technology. The software is being used to treat flying and social phobia. The patients can experience the virtual environment with the help of Head-Mounted Displays (HDMs) and observe the entire environment all around them. Meanwhile, psychotherapists have full control on changing the environment by increasing or decreasing the complexity level.

Spider-World [10] is a computer-based VR therapy with an additional ability feature to feel the object. As the name suggests, it is used to treat patients with spider phobia. Under this treatment, the patient can touch a virtual spider with the help of a cyber hand, generating the illusion of a spider touch. Certainly, this type of tactile augmentation doubled the effectiveness of VR treatment by improving the patient confidence level towards the phobic stimulus.

Phobos is VR software developed by PsyTech LLC [11]. It was specially designed to treat phobic patients using a gradual approach. The software is based on VR Exposure Therapy (VRET). It provides private environments for the patients to manage their anxiety symptoms, including interactive VR environments of some phobias such as flying, height, spiders and crowded spaces.

The VR medical center [12] was established in the USA with the purpose of treating phobic patients in the most suitable, affordable, and convenient way. The medical center has the VR equipment and the required software to make the treatment possible. The center currently treats a number of phobias, including fear of flying, driving, public speaking and thunderstorms. The medical center uses the Cave Automatic Virtual Environment (CAVE) and HDM setups to treat patients.

In addition, numerous mobile applications have been developed under this context. Beat Social Phobia [13] was developed by Andrew Johnson, a clinical hypnotherapist, and released by HiveBrain Software in 2013. It is an app that provides audio instructions from the psychotherapist to think in a more positive way. It helps to identify the specific phobia, its symptoms and how to deal with it. It helps to become more confident, relaxed and calm in social places. The Beat Social Phobia app sessions are twenty-six minutes long and divided into four parts: introduction, relaxation, social phobia and awakening. However, it does not provide any video tutorials or immersive environments for the phobic patient. Thus, the patient cannot experience the actual situation causing the phobia (virtually).

Byten Phobia Treatment [14] was developed by Paul Mckenna in 2013 and released by Once Byten Limited. It runs on iOS and provides an audio session. The patient can select one of the phobias from the list, listen to the sessions at their own pace and try to think in a different manner towards the phobic agent. This app has some weaknesses such as it does not offer videos or exposure therapy environment for agents which does not help the real experience of the phobia itself. The option to reverse the audio session to a specific point is not offered, so the user has to listen to the whole session again. Quite often, the app freezes and does not response at all.

Cure Phobias and Overcome Fear [15] is an Android app developed in 2009. It is offered by MasterMind Apps and also provides an audio session of therapy that is meant to promote positive thinking in users to overcome their personal problems. It gives a textual description of the phobias and provides tips to overcome them. It contains some flaws such as unfriendly user interface and the audio session is quite long, causing loss of attention. Sometimes, the audio does not play at all and, occasionally, becomes unresponsive.

Arachnophobia Free app [16] has been developed in association with two leading psychiatrists to treat people with spider phobia. It is offered by Thrive Technologies Limited. The app is supported by iOS and it is based on VRET where patients are exposed to spiders in a gradual manner. In early stages, the spider is represented as a little cute pink character named “Itsy” and, as the game progresses, it turns to a real looking spider. The user can retake the session to get over their fear. The app provides guided therapy with the help of a virtual doctor called Dr. Freeman. The app presented in [17] is of high quality and has been winner of Cambridge University Technology and Enterprise Club (CUTEC) at Cambridge University. However, its drawback is that it treats a single type of phobia.

Created by Malmum Developers, VR Height Phobia addresses height phobia [18]. It has three levels, and the users may easily navigate through them and may repeat any level until they become comfortable. However, it has poor graphics, and the user has to launch the app again after completing each level.

Developed by Virtual Speech, the goal of the Public Speaking VR [19] app is public speaking phobia treatment. The scenes are provided with many people seated and some distractions are created with noise and voice of people talking. This helps the app user to boost his/her self-assurance to face the real settings confidently. Some of the setbacks include blurred transitions while, sometimes, the splitting screen does not work.

Our contribution in this field is a mobile application that assists patients with exposure therapy sessions at any time with ease and lets them face their own fear. It is designed to provide an affordable therapy instead of costly treatments and to avoid long waiting hours for appointments. Since the environment is controlled and gradual, the users can repeat the sessions at their own will. There are several levels of treatment that the patient might be gradually exposed to. As the patient becomes more comfortable, s/he can move to a more intense level. Furthermore, patients can learn about the different types of phobias and their respective symptoms through the application. In addition, the application assists the user to search for a psychotherapist in the selected location (UAE in our case) and to make an appointment. Finally, it is worth mentioning that our application can run on iOS and Android platforms.

III. FYF APP

A. Pre-Survey

To develop a fully functional and good quality VR mobile app that helps with the treatment of phobias, a survey was conducted among people of different ages, genders, and professions. The data collected provided a quantitative insight into phobia related questions. In addition, the obtained feedback from Survey Monkey helped in the elicitation of requirements and features to be considered when developing the app.

The gender participation ratio was 64% females and 36% males. The age distribution was as follows: 70% in the range of 18-24 years, 13.5% in the range of 25-34 years, 10% in the range of 35-44 years and 6.5% in the range 45-54 years. Of the 77 respondents, 72.73% live in the UAE while the remaining ones live outside of the UAE (Palestine, Syria, Turkey, KSA, Germany, Egypt). The main purpose of knowing the respondent's location is closely related to some countries phobias patterns. This happens because phobias are frequently based on each local environment factor.

Participants were given a phobia list and were asked to select the one(s) they suffer from. The results were as follows: 4.22% - arachnophobia; 8.42% - claustrophobia; 6.85% - glossophobia; 13.51% - aquaphobia; 11.81% - acrophobia; 12.43% - achluophobia; 6.85% - avidophobia; 8.56% - entomophobia; 4.43% - hemophobia; 9.59% - ailurophobia; 13.33% - other responses included war, fighting, sexual assault, my wife, snakes, cockroaches or not having phobia at all.

Another inquiry was closely related to whether the participants' phobia was related to a specific event. 84.42% of them simply stated no. Furthermore, to help understand the symptoms that occur when a person encounters the phobic agent, the most common symptom (50%) was rapid heartbeat. Some respondents specified other side-effects such as trouble breathing, panic attacks, shaking, nausea, running away and sweating.

For those who have phobia, 54.67% of the respondents stated that they searched already for a specialist. Concerning the preference of way of treatment, 17.14% favor treatment with pills while 82.86% prefer treatment by exposure to the feared object/situation. The last question was related to the adoption of a mobile application for phobia treatment. 63.51% were positive towards this idea.

B. Development

The FyF App consists of a three-layer framework composed of the presentation, business and data layers. The presentation layer contains the user interfaces which represent the scenes and was developed in Unity. The business is a service layer that contains Java (JS) and C# scripts to interact with the data layer for processing purpose and to display the scenes and give the appropriate feedback to the end-users.

This VR-based phobia app runs on Android OS for smart phones. It also requires the use of VR glasses, such as Google Cardboard [20], which come in an affordable cost and in order to experience the phobia environment. The users of the app are phobic patients and the psychotherapist. The patient is the one who experiences phobia environments. S/he has the option to search for a nearby psychotherapist and to send the experience feedback from the app to the psychotherapist. For the psychotherapist, s/he may use the app to receive the patient experience outcome and to discuss/follow up with the patient.

In its development, several software packages have been used to create realistic and high-quality scenes, including animations and audios to provide a realistic and natural experience for the end-user. The game engine choice was Unity3D [21] with its nice feature of multiple OS platforms. In a reference note, Unity is a game engine that supports simulations, desktop, websites and apps, including a Software Development Kit (SDK) for virtual and augmented reality. Google SketchUp [22], a powerful and user-friendly Computer Aided Design (CAD) created realistic effects. Max 3D [23], used to develop 3D animations, models and characters, provided realistic and professional graphics and it has been used to develop some extra VR environment features. Audacity audio editor provided multiple features of music editing and merging recording sounds. It was used to develop sound effects of water waves and darkness sound at night for the aquaphobia and achluophobia environments. Blender Software has been used to create 3D models and developing characters, videos and audios. It offers animations and high-quality graphics. Besides, it also supports natural environment and object creation such as raindrops, flames, smoke, rainbows and sky movements. Cardboard SDK, a VR based support compatible with Unity to develop VR applications, has been also exploited to develop immersive environments.

In the phase of system analysis and requirement elicitation, meetings and interviews have been conducted with a psychotherapist in Abu Dhabi. In addition, a thorough literature search has been done to get an insight into the existing methods of phobia treatment.

C. GUIs

A set of interfaces has been designed by considering the usability and user experience, where the displaying menus and functions are clear, the navigation is easy, the colors are well-chosen, the images are clear, and the text font size is suitable. Figure 1 (left) presents the screen when the user first launches this app (it stays for 5 seconds) while Figure 1 (right) presents the main screen with three options: “Experience VR”, “Get to Know Phobia”, and “Nearby psychotherapist”. It was designed as a wheel with graphical icons for each selection.

Figure 1. Welcome (left) and main (right) screen.

The “Experience VR” screen (Figure 2) gives the user two options to select: (A) Water phobia (aquaphobia); (B) Darkness phobia (achluophobia). Afterwards, s/he will be directed to the “Session” screen. For any new VR user, it is advisable that s/he chooses a short session first although real treatment requires long ones (30 minutes, according to doctors). Additionally, the session level time is setup automatically. The scenes for the three levels of aquaphobia and achluophobia are revealed in Figures 3 and 4, respectively.

Figure 2. “Experience VR” (left) and “Session” (right) screen.

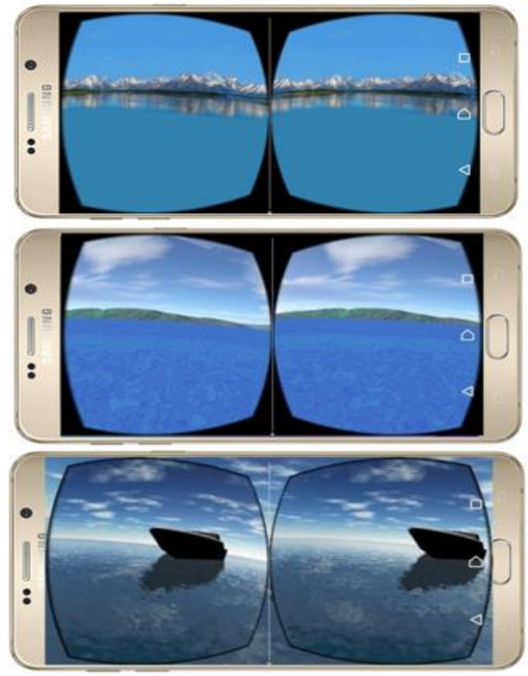

Figure 3. Aquaphobia level 1 (top), level 2 (middle) and level 3 (bottom).

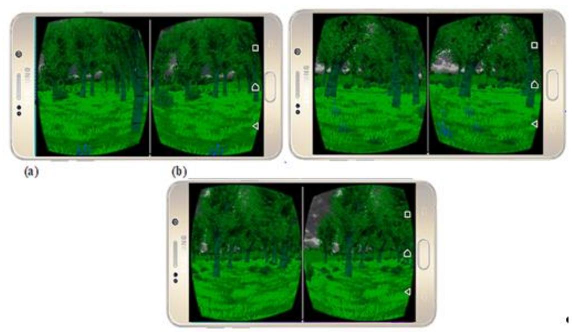

Figure 4. Achluophobia (a) level 1, (b) level 2 and (c) level 3.

The “Nearby psychiatrist” helps the user to find the nearest psychotherapist, as shown in Figure 5. For that, the user selects the city from the list box menu. Once the city is selected, another sub-menu listing all hospitals that have a psychiatry department is shown to the user. For usability purposes, we opted for list boxes to make it easier rather than typing the name of the city and hospitals and, naturally, to reduce user typos. When a hospital is selected, the address and telephone numbers are disclosed.

Our proposed app, FyF, has been tested from the functionalities and usability perspectives. A group of students from the university in Abu Dhabi have been selected to test our app. The selected participants suffer from the above-mentioned types of phobias. The overall results have shown to be promising. However, this testing phase requires long time and, more importantly, requires the opinions of psychotherapists in the field, which is our next step in the plan.

Figure 5. The nearby psychotherapist screens.

IV. CONCLUSION AND FUTURE WORK

In this paper, a VR-based mobile app is proposed to assist phobic patients. It has an easy-to-use interface to be used for the initial treatment. It provides patients with appealing features, such as virtual exposure to the phobic situations or objects, textual descriptions on types of phobias, their symptoms and treatments, search function for nearby psychotherapists, audio that helps them to relax and report submissions capabilities to his/her doctor. This app also provides the virtual environment for patients to gradually get exposed to each stimulus to overcome their fear. Patients may experience a 360-degree view of the phobia agent environment along with sounds to provide a realistic scene. At last, users can turn on music when they feel uncomfortable or move to higher exposure levels.

As future improvement, we plan to gather feedback from experts in the field such as psychotherapists in case our app needs improvements. Also, we plan to add the use of a smartwatch to be connected where, during any VR session, the user heart rate is being monitored. In the case the heart rate becomes high, the user will be given an option to exit or play a calm audio. If the heart rate exceeds a certain rate (100 bpm for adults), the session will be closed automatically. Additionally, we plan to extend the app to add other types of phobias.

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ShareHandy: Peer Teaching Support System for Online Exercises of IoT Prototyping

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***Abstract*— Peer teaching is said to be one of the most useful means for students to learn deeply. However, in online exercises for assembling hardware, students cannot easily share their hardware assembly status among them, which hinders peer teaching among them. To solve this problem, we developed a hand-sharing system, ShareHandy, which allows students to share video images showing their work in progress hardware with their smartphones. This paper proposes the system, describing its design and rationales, and verifies the usefulness of the system through an experimental exercise of Internet of Things (IoT) prototyping. The results show that the proposed system can effectively promote peer teaching and improve the efficiency of the exercise.**

Keywords-online education; peer-teaching; IoT exercise.

I. Introduction

Peer-teaching is a learning method in which students teach each other and is attracting attention to increase the learning effectiveness of students [1]. Recently, the COVID-19 pandemic has increased the number of online classes and exercises. However, such online situation also limits the interactions among students to online, making it difficult to hold peer teaching [2]. One of the major reasons for this is that it is difficult for students to share their assembly status of hardware with the other students. For example, when students are learning electric circuits online, they lose important peer-teaching opportunities, such as sharing one student's work with the teacher and other students, pointing out and giving advice to each other interactively, and being able to review the points and advice after that.

To solve this problem, Dorneich et al. clarify the classification and criteria for online classes [3]. Kitagami et al. propose an exercise method of using a virtual camera to share camera images, documents etc. in one screen in a Web conference system, in which students watch the screen image transmitted by the teacher as they proceed with the exercises [4]. However, this method does not allow students to see other students' status while receiving teacher's transmission. Hamblen et al. proposed a method for peer teaching of hardware assembly in an asynchronous environment using a wiki [5]. However, this method does not allow students to interact with each other in real-time.

To solve the above problems, we propose a peer teaching support system ShareHandy, which provides the function for students to share their assembly status of the hardware with a camera, point and draw on the shared images, and save these images data. The proposed system allows students to facilitate real-time peer teaching within a group.

This paper first presents the requirements for a peer-teaching support system, the corresponding design, and its rationales, describes the prototype implementation, and evaluates its usefulness by applying it to a group exercise of Internet of Things (IoT) prototyping held online. The results show that the proposed system allows students to understand each other's situation quickly and accurately in group work exercises. Therefore, the proposed system has proven useful in supporting peer teaching.

In this paper, Section 2 presents the details of our proposal system, Section 3 and Section 4 describe the experimental evaluation, and their results and discussion, and Section 5 concludes this paper.

II. Proposed System

To support peer-teaching in IoT prototyping exercises, it is necessary to have a support function for the teacher and the students to share the hardware assembly status. The basic function of the proposed system is to stream live videos of students' at-hands using their own smartphone camera for peer-teaching.

The following subsections describe the assumptions and scenarios of using the proposal system, the functions provided by the system, and how these functions can be utilized in the scenarios.

A. Usage Assumptions and Scenarios

We assume that the exercises to be supported are designed for each student to work in a group and assemble the same hardware individually. The group can use the support functions to discuss and teach each other within each group. The proposed support system works as an auxiliary system for the Web conferencing system, which handles document sharing and voice communication. This support system helps the group members share the video images of their work in progress.

The following scenarios are considered as the major use of the support functions.

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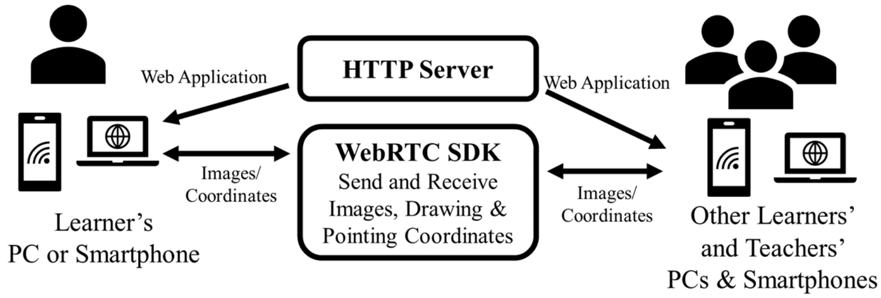

Figure 1. System Structure of ShareHandy

- Students who have successfully completed the assembly and those who have not work together to review their work each other's work to find out what the problems are.
- A student asks the teacher some question about how to proceed with the exercise, and a session is held to answer the question. Several students who are interested in the questions participate in the session, and the session proceeds on a question-and-answer basis.

B. Designed functions and their usage scenarios

1) Setting up rooms for group sharing

The system is designed to set up multiple rooms simultaneously so that some group members can easily have a space to discuss some topic and other members interested in it can participate freely.

2) Real-time video streaming

Using cameras of smartphones or Web cameras attached to laptops, images of multiple students' work-in-progress artifacts are streamed in real-time. The system can display multiple images at the same time so that the students can see each other's at-hand work at the same time. This allows the person teaching the session to communicate the correct sequence of steps in a work, the changes on the artifact for each work step, and the person being taught to communicate how his/her work has been progressing so far and what the problems are. In addition, the system can convey information enabling a three-dimensional recognition of the artifact through video, which cannot be conveyed by documents or still images.

3) Pausing video and broadcasting still images

The video being streamed can be paused and streamed as a still image. This allows the person teaching to take enough time to give a detailed explanation of the work steps of focus and their key points, and allows the person being taught to be able to stop at his/her problematic work points to ask questions to investigate what is wrong.

4) Pointing by participants

Each participant has a cursor with an individual identifier and can point to a certain position on the video image. This allows the person teaching to clarify the points of focus, explain the situation, and give instructions accurately. It also allows the person being taught to clarify the points to ask.

5) Drawing by participants

Participants can use their fingers, pens, mouse, etc. to write texts and draw figures on the streaming videos (including still images). This allows the person teaching to label related locations (e.g., name and number in the image locations) and to indicate directions drawing arrows. In addition, the person being taught can leave notes to be shared.

6) Saving video captures and drawings as still images

A still image of an arbitrary video scene with drawing data overlaid on it can be stored on the participant's device. This allows the person being taught to reflect on the session through self-study afterwards.

C. Implementation of the Proposed System

The proposed system is implemented as ShareHandy, which enables easy sharing of the sight at hand. The structure of ShareHandy is shown in Figure 1.

The system is designed to work on any devices such as PCs and smartphones. Therefore, this system is built as a Web application, which runs on a Web browser and has the advantage of being able to support multiple operating systems with a single code. Another advantage is that users only require access to a web page for using the application and there is no need to install additional applications on each device.

As shown in Figure 1, we use WebRTC (Web Real-Time Communication), which enables real-time communication of video, audio, and general data via a Web browser [6]. WebRTC communication allows the users to send and receive images, coordinates of drawing and pointing, and other control signals in real-time.

Figure 2 shows an example of using ShareHandy. Two people participate in a session, sharing videos showing their artifacts. In the left screen, the pointers of the participants (shown with a "P" mark) and the drawing data are displayed.

III. EXPERIMENTAL EVALUATION

A. Purpose of the Experiment

We formulate two hypotheses concerning the effects that can be achieved by using this system in online exercises.

Figure 2. User Interface of ShareHandy and Demonstration

[Hypothesis 1] This system makes it possible for the person teaching to quickly and accurately covey a set of instructions on the artifact at hand to the person being taught.

[Hypothesis 2] This system enables group work to be carried out smoothly, and as a result peer teaching can be promoted.

We conducted experiments to test these hypotheses.

B. *Method of the experiments*

1) *Exercises to which the method is applied*

Two exercises on IoT prototyping:

- Individual exercises following a sample procedure, where every student belongs to some group, whose members can communicate within it.
- Project-based learning style exercises, in which each group develops a prototype to solve their problem.

2) *Subjects*

10 undergraduate students and 4 graduate school students. All subjects were students at Shibaura Institute of Technology, and majored computer science and engineering.

3) *Experimental procedure*

The subjects formed small groups of three to four people, and the groups were asked to use ShareHandy freely during the exercises. We did not instruct where and how to use it in particular.

4) *Evaluation method*

We asked the subjects to answer a questionnaire after finishing the exercises. We analyzed their answers to evaluate the results of the experiments. The questions in the questionnaire are shown in Table 1. In addition to this, we directly interviewed the subjects after the exercises.

C. *Result of the Experiment*

We receive 14 answers from all the subjects. The results of the questionnaire are shown in Table 2.

- Concerning the answers to Q3-1, 86% of the subjects answered positively to the question “Was it easy to see the other person's hand?” In addition, all the subjects felt positive about Q3-2 “The other person quickly understood my situation” and Q3-4 “It was easy to communicate by pointing with my hand.” Furthermore, 86% of the subjects answered positively to Q3-5 “I was able to proceed with the work efficiently.” From these results, we can confirm that our hypothesis 1 is true, that the system achieves the targeted effect and allows the subjects to covey instructions on artifacts at hand quickly and accurately.
- To Q3-5 of " It lowered the barrier for teaching each other", all the subjects answered affirmatively.

In addition, 92% of the students answered affirmatively when asked if they would like to use this system again, suggesting that using this system is useful.

From the interviews with the students after the experiment, we obtain the following points of their impressions and dissatisfaction.

Positive comments include:

- Because handling the objects can be easily seen, it is easy to understand how they are built Because objects at hands can be easily seen, how they are built can be understood well (from many subjects).
- Because group members can share the view of the objects at hand, it is easy to explain them. It can also be used to check if the right sensor has been selected.

The latter comment suggests that we can apply this system to much broader things than we originally expected.

Negative comments include:

- The screen of the smartphone is too small to see the screens of other participants.
- Because the camera does not focus well, it is difficult to see small characters.

These negative comments suggest a need for improvement on both the system itself and the way to use it.

IV. DISCUSSION

We found that the proposed system effectively achieves the effects that we targeted in the design of the system from the answers of Q3-1 to Q3-4. Therefore, the system allows all

TABLE I. QUESTIONS ON THE QUESTIONNAIRE ADMINISTERED AT THE END OF THE EXPERIMENT

No.	Questions and Options
Q1	What is your position?
Q2	In what situations did you use the system? · Teaching each other in the group · Creating something with the group member · Teaching each other with one-on-one
Q3	Please answer the following questions in four choices: Agree, Almost Agree, Almost Disagree, or Disagree
Q3-1	It was easy to see the other person's hand.
Q3-2	Groupmates understood my situation right away.
Q3-3	I was able to work efficiently.
Q3-4	It was easy to communicate by pointing at the hand.
Q3-5	It lowered the barrier for teaching each other.
Q3-6	I would use this system again.
Q4	Any other comment (Free text)

TABLE II. RESULT OF THE QUESTIONNAIRE

No.	**Question**	**Answer**			
Q1	What is your position?	**Undergraduate Student**		**Graduate Student**	
		10		4	
Q2	In what situations did you use the system?	**Teaching each other in the group**	**Creating something with the group member**	**Teaching each other one-on-one**	
		7	7	0	
Q3	Please answer the following questions	**Agree**	**Almost Agree**	**Almost Disagree**	**Disagree**
Q3-1	It was easy to see the other person's hand.	9	3	2	0
Q3-2	Groupmates understood my situation right away.	7	7	0	0
Q3-3	I was able to work efficiently.	10	2	2	0
Q3-4	It was easy to communicate by pointing at the hand.	8	6	0	0
Q3-5	It lowered the barrier for teaching each other.	7	7	0	0
Q3-6	I would use this system again.	5	8	1	0

the participants (including teachers and students) to share the status of multiple participants' hardware in real-time (Hypothesis 1). Moreover, directly from the answers to Q3-5, we found that the system promotes peer teaching.

From the results of the questionnaire, the level of satisfaction in using this system is high. This is because there is no other way for students to see the others' hands in real-time. The real-time nature of the system and its pointing function may have increased the user's satisfaction.

However, the system has not been used very often during the exercises, with the usage frequency being lower than we expected. Some students commented that:

- The system is easy to use, but we did not have so many opportunities to use it.
- We did not have so many problems relating to hardware in IoT prototyping.

The IoT prototyping used in the experiments does not have so many complicated tasks relating to hardware which need someone's help. In addition, we guess that online exercises may create a sense of emotional distance between students. This may be the reason why many students hesitated to ask the other group members a question or preferred to research the answer on their own instead.

To overcome such limitations for the validity of the experimental evaluation, we need further experiments that include giving the subjects a method to decrease the hesitation in communicating online or giving them a problem on IoT prototyping with a high level of hardware difficulty.

V. CONCLUSION

We developed a web application, ShareHandy, which can be used in the context of hardware assembly to share video images showing hardware assembly status with the other students. Our experiment to confirm its usefulness in improving comprehension and peer teaching gave positive results from students who used the system. The results of the questionnaires and interviews suggest that the system is effective enough to support group work and peer teaching.

Through this study, we found some issues such as the search for an effective way to use the system for online exercises, the improvement of the accuracy of the system, and the evaluation method of the system.

In future work, we will improve the reliability and usability of the proposed system, find an effective way to use it in online exercises, and solve the problem of video quality. In addition, we will apply and evaluate the system on a larger number of subjects and explore better evaluation methods through quantitative data measurement.

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A Method for Analyzing Improper Driving Using Passenger's Danger Perceptions

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***Abstract*—One of the main causes of traffic accidents is "improper driving", such as driver's carelessness and operation mistakes. To prevent traffic accidents, it is necessary to detect the occurrence of improper driving, point it out to the driver, and advise improvement. However, the driving behavior analysis method, which analyzes the driving itself from several sensor data, cannot accurately and comprehensively detect improper driving because it cannot consider the traffic situation related to the road, the other vehicles and so on. This paper proposes a method that combines the driving behavior analysis method and the danger perception by passengers. This method enables us to detect improper driving comprehensively and correctly because passengers objectively see both the driving and traffic situation. We conducted experiments of applying this method and confirmed its usefulness.**

Keywords-Drive Analysis; Heart Rate; Passenger.

I. INTRODUCTION

Traffic accidents caused by automobiles are one of the many serious problems in the modern society. One of the major causes of traffic accidents is the driver's improper driving [1], including driver's operational errors and carelessness.

To prevent traffic accidents caused by such improper driving, a support system that points out its occurrence and provides advice for improvement will be useful for the driver. Driving behavior analysis uses sensors to measure the behavior of a car caused by driving to detect abnormal driving patterns, such as rapid acceleration and meandering as improper driving. However, the driving behavior analysis does not have a high degree of accuracy because only a few driving patterns can be analyzed without traffic conditions in which the driving takes places. Therefore, it is often the case where the driving behavior analysis wrongly determines improper driving or even misses improper driving altogether. This problem can be a major drawback for the support system to give appropriate advice to the drivers.

To solve this problem, we propose a method that utilizes the passenger's danger perception on the traffic situation in addition to the driving behavior analysis. The proposed method analyzes the variation of the passenger's heart rate to detect the passenger's danger perception. Next, the detected danger perceptions are compared to the abnormal driving patterns detected by the driving behavior analysis. If they are matched, the detected patterns are considered improper driving. In addition, there are many cases of improper driving that cannot be detected by driving behavior analysis because they are strongly dependent on the traffic conditions. The method analyzes the passenger's danger perceptions that do not match the abnormal driving patterns to extract such cases. This makes it possible to detect improper driving comprehensively and correctly.

To implement the proposed method, we firstly devise a way to detect passenger's danger perceptions by analyzing his/her heart rate variability based on some experiments. The experiments consist of a measurement method and judging criteria for heart rate abnormalities.

We secondly conduct an experiment to show that our method works as expected. The results of the experiment show that the passenger's danger perceptions are useful to improve the accuracy of detecting the improper driving, and the passenger's danger perceptions that do not match the abnormal driving patterns, called danger-perception-only data, include many cases of improper driving. However, some of the abnormalities detected in the passenger's heart rate are not related to improper driving, and so it is necessary to exclude them from the danger-perception-only data to utilize them.

Section Ⅱ of this paper describes the existing methods for detecting improper driving and its problems; Section Ⅲ proposes our method in detail; Section Ⅳ describes an experiment and its results, and Section Ⅴ discusses them, to show the validity and remaining issues of the proposed method; Section Ⅵ concludes this paper.

II. EXISTING METHODS FOR DETECTING IMPROPER DRIVING

A. *Driving behavior analysis*

Driving behavior analysis is an analysis method that detects dangerous driving patterns by collecting and analyzing sensor data on the motion state of a vehicle while driving [2][3]. The sensor data includes speed, acceleration, and angular velocity. These data are used to detect dangerous driving patterns, such as sudden braking, sudden steering, sudden acceleration, and unsteady handing. This method has been already used in many cars to analyze the driver's

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driving to provide cautions and advices to the driver on the occurrence of improper driving. However, this method has a problem that it cannot detect improper driving accurately due to the following reasons:

- The information that can be obtained from existing sensors is too little to cover all the abnormal driving patterns to analyze.
- Because of no consideration of traffic conditions, the analysis often results in incorrect judgment of improper driving.

Concerning the latter, this is because the criteria for judging whether a certain driving is improper or not vary depending on the traffic conditions in which it is taken place. That is, the improper driving can be correctly determined by the combination of driving operations and traffic conditions.

B. Driver's danger perception

Another approach to analyzing improper driving is to estimate the danger perception while driving from the driver's own physiological data. There exist several methods to adopt this approach:

- Detection of the occurrence of danger by using heart rate variability while driving [4]
- Monitoring some visual behaviors that characterize a driver's level of vigilance [5]
- Estimation of the driver's emotions [6]

These methods can detect the driver's danger perception when capturing external dangers, such as unexpected events or unsafe situations.

Since the driver's perception of danger comprehensively captures all the driving situation including driving behavior and traffic conditions, it is expected to get more comprehensive information the driving behavior analysis cannot obtain, such as pedestrians' sudden crossing or the other vehicles' improper driving.

On the other hand, this method has the following problems:

- There are individual differences in the human heart rate and its changes, and these individual differences affect the accuracy of hazard detection.
- Since the change in heart rate is not an event that occurs only when a danger is recognized, events other than danger recognition while driving may be detected.
- Because drivers recognize the situation subjectively, i.e., they tend not to think their driving has problems, the driver's perception of danger is not suitable to use for judging improper driving.

III. PROPOSED METHOD

A. Approaches

To solve the problems of the existing methods in the previous section, we adopt an approach to use the passenger's danger perception. Because the passenger's perception of danger is more objective that the driver's one, its combination with the driving behavior analysis is expected to work well.

B. How to determine improper driving

The proposed method for detecting improper driving using the passenger's perception of danger is shown in Figure 1.

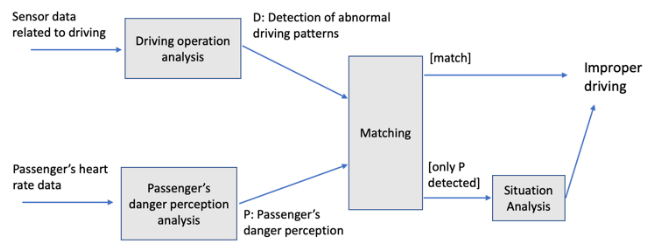

Figure 1. Proposed method for detecting improper driving using passenger's perception of danger

The method first does the driving behavior analysis using sensor data, such as Global Positioning System (GPS) speed and angular velocity to detect abnormal driving patterns. Next, it analyzes the variation of the passenger's heart rate to detect the passenger's danger perception. After that, the detected danger perceptions are compared to the abnormal driving patterns detected by the driving behavior analysis. If they are matched, the detected patterns are considered improper driving. In addition, there are many cases of improper driving that cannot be detected by driving behavior analysis because they are strongly dependent on the traffic conditions. The method analyzes the passenger's danger perceptions that do not match the abnormal driving patterns to extract such cases. This makes it possible to detect improper driving comprehensively and correctly.

C. Passennger's danger perception analysis

The proposed method uses the danger perception analysis, which detects human danger perception by analyzing the variation of the heart rate to find out the occurrence of its abnormalities. Through an experiment, we defined the following two types of abnormal heart rate patterns.

- Rapid increase in heart rate: As shown in Figure 2, when the amount of change in heart rate increases above the specified threshold within a certain period of time, it is determined that there is a rapid increase in heart rate. The heart rate is measured every second, and the threshold of the amount of change is 10 beats.

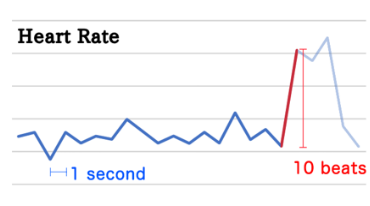

Figure 2. Heart rate variability during rapid heart rate increase

- High heart rate state: As shown in Figure 3, when the heart rate value stays high for a certain period, it is judged to be in a high heart rate state. The heart rate is judge as high when it is over the threshold of the average heart rate plus 10.

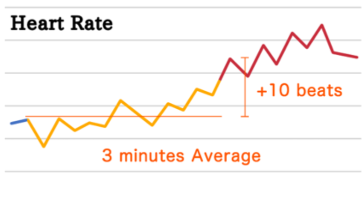

Figure 3. Heart rate variability during high heart rate state

The average heart rate is determined based on the measurement in the last three minutes. This makes it possible to compensate individual differences in the passenger's heart rate.

IV. Experimental Evaluation

A. *Purpose of the experiment*

The following two hypotheses, which support the theoretical basis of the proposed method, are verified by actual driving experiments to work as expected.

- Hypothesis 1: False positives for improper driving will be reduced by looking at the match between abnormal driving patterns based on the driving behavior analysis and danger perception based on the passenger's danger perception analysis.
- Hypothesis 2: There exist some danger perceptions that do not match abnormal driving patterns, which include most of all the improper driving that strongly depends on the traffic conditions, which cannot be detected by the driving behavior analysis.

B. *Experimental methods*

In the driving experiment, the speed and angular velocity of the vehicle and the heart rate of the passenger are measured every second while driving. The vehicle's speed and angular velocity are measured using the smartphone's sensors, and the passenger's heart rate is measured using the Apple Watch's optical heart rate sensor. One experiment consists of one-hour driving. After the driving, the actual driving situation was reviewed using video and notes recorded during the driving. Figures 4-7 show how the experiment took place.

- Figure 4: smartphone sensor that measures the vehicle's angle and angular velocity.
- Figure 5: Apple Watch measuring the passenger's heart rate.
- Figure 6: video camera on the windshield recoding the vehicle's forward image.
- Figure 7: Passengers taking notes when they perceive a danger.

In this experiment, we use a prototyping system implementing the proposed method in Figure 1, except for Situation Analysis, which is performed based on the passenger's own judgement by reviewing the recorded video after the experiment.

The subjects of this experiment are 17 university students with different driving experiences, and 50 sets of experiments took place. Table 1 shows the breakdown of the driving experience of the passengers, and Table 2 shows the breakdown of the combinations of driver and passenger by driving experience.

Figure 4. Measurement of vehicle speed and angular velocity using smartphone sensors

Figure 5. Measurement of passenger's heart rate using Apple Watch

Figure 6. Recording of the vehicle's forward image using a video camera

Figure 7. Passengers taking notes when they perceive a danger.

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TABLE I. BREAKDOWN OF PARTICIPANTS IN THE DRIVING EXPERIMENT

Participants' driving frequency	Number of people	Number of experiments
Drive on a daily basis	5 people	12 sets
Sometimes drive	4 people	10 sets
Don't usually drive	4 people	13 sets
No driver's license	4 people	15 sets
Total	17 people	50 sets

TABLE II. BREAKDOWN OF DRIVERS AND PASSENGERS BY DRIVING FREQUENCY

Driver's driving frequency	Passengers' driving frequency	Number of experiments
Drive on a daily basis	Drive on a daily basis	7 sets
	Sometimes drive	1 set
	Don't usually drive	8 sets
	No driver's license	4 sets
Sometimes drive	Drive on a daily basis	5 sets
	Sometimes drive	9 sets
	Don't usually drive	5 sets
	No driver's license	11 sets
Total		50 sets

C. Results of experiments

1) Hypothesis 1

A total of 56 abnormal driving patterns are detected by the driving behavior analysis. Of these, 9 cases match the passenger's danger perception. Figure 8 shows all the cases classified into four danger levels by the review of actual situation.

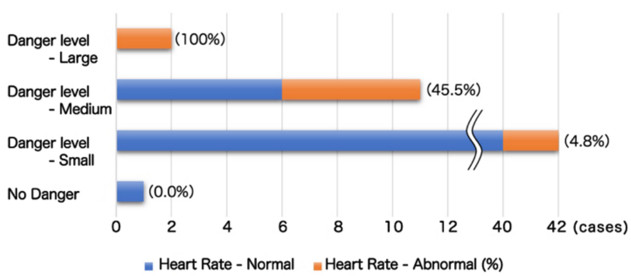

Figure 8. Relationship between abnormal driving patterns and passengers' perception of danger

Figure 1 shows that the passenger's danger perception responds in most situations where the actual danger level is high, and in contrast, the passenger's danger perception does not respond in most situations where the actual danger level is low. In this way, there is a tendency that the group of abnormal driving classified in higher danger level have more percentage of ones matching with passenger's danger perception. This proves Hypothesis 1 that false positives for improper driving in the driving behavior analysis can be reduced by using the results of the passenger's danger perception analysis.

2) Hypothesis 2

Of the results of detecting passenger's danger perceptions, 142 cases do not match the abnormal driving patterns. Table 3 shows the results of categorizing their causes based on the review of the actual situation one by one.

TABLE III. CATEGORIZATION OF THE ANALYZED CAUSE OF PASSENGER'S HEART RATE ABNORMALITIES

Dangerous driving	Outside threats	Emotional change	Unknown cause
18 cases	43 cases	62 cases	19 cases

Details of each item used in the classification and examples of actual occurrences are as follows.

a) Dangerous driving: 18 cases

- Anxiety or fear felt about the driver's dangerous driving (e.g., accelerating instead of stopping at a traffic light change, etc.)

b) Outside threats: 43 cases

- Perceived danger due to external factors, such as interruptions by other vehicles or pedestrians jumping out (e.g., a driver suddenly getting out of a stopped truck)
- Anxiety caused by environmental factors, such as narrowness of the road and poor visibility (e.g., glare from the western sun, thick fog, etc.)

c) Emotional change: 62 cases

- Excitement or surprise during conversation
- Drowsiness and fatigue

Hypothesis 2 proves correct, from the fact that many improper driving cases are included in the passenger's danger perceptions that do not match abnormal driving pattern, and few improper driving cases are seen that are not detected by either analysis.

However, the results showed that there are some cases other than improper driving among the passenger's heart rate abnormalities.

V. CONSIDERATIONS

From the fact that passenger's heart rate abnormalities have a correlation with the actual danger level of abnormal driving patterns, we found that our approach to using passenger's danger perceptions to reduce the false detection of improper driving is reasonable. In addition, we also found that the passenger's danger perceptions can cover most improper driving situations that the driving behavior analysis cannot detect. These results show that the proposed method can detect improper driving comprehensively and correctly.

However, the important issue to be settled to establish our proposed method is that there are some cases other than improper driving among the passenger's heart rate abnormalities, and therefore it is necessary to separate true danger perceptions from these cases to utilize them.

Moreover, we have not yet proved that the passenger's heart rate abnormalities are better than the driver's ones to capture the objective danger perception. We need to conduct

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further experiments, in which we collect both driver's and passenger's heart rate data at the same time.

Concerning the subjects of our experiments, we used almost the same aged university students, but it is necessary to use a wider variety of subjects to increase the validity of the experiments. Furthermore, to establish the proposed method, it is necessary to realize a method to analyze the passenger's danger perception that does not match abnormal driving patterns. However, it is difficult to do so at this moment because it requires a comprehensive understanding of the factors that cause the abnormal heart rate patterns to devise how to extract only true danger perceptions.

VI. CONCLUSION

In this paper, we proposed a method for detecting improper driving using driving behavior analysis, combined with the passenger's danger perception. The driving experiments showed that the proposed method can reduce the number of false positives for improper driving, and that it includes most of improper driving that the driving behavior analysis cannot detect because it strongly depends on traffic conditions. However, the passenger heart rate abnormalities include many cases not relating to improper driving, which need to be excluded.

In the future, we will further investigate the method for separating heart rate abnormality cases not related to improper driving. In addition, we will conduct more experiments to clarify the differences of causes of driver's and passenger's heart rate abnormalities and the differences in heart rate fluctuation due to driving experience.

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An Architecture for Detection of Anomalies in Deterministic Time within Real-Time Communication Networks

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***Abstract*—Anomaly detection is a classical and important topic within the domain of communication networks. For critical applications, the time it takes to detect an anomaly and to respond to it is an important metric of an anomaly detection system. To address this, we propose an end-to-end real-time anomaly detection architecture. In this architecture, the collection and transmission of the required data, the analysis of this data in a machine learning model and the subsequent reaction when an anomaly is detected, are carried out in deterministic time. We study two different use cases where this architecture may be applied in the future and we investigate a demo implementation of one of these use cases as a proof of concept for the proposed architecture. This contributes to the future application of machine learning for anomaly detection in deterministic time in time critical application areas.**

Keywords—machine learning; real-time Ethernet; anomaly detection.

I. INTRODUCTION

Real-time communication networks and the application of Machine Learning (ML) methods to such networks is a current research area in the networking domain. Anomaly detection is one example where ML methods have been successfully applied to detect abnormal behaviour in (non-real-time) networks. With the increasing relevance of real-time communication networks in cyber-physical systems in critical domains, such as manufacturing and smart energy grids, solutions for applying ML approaches to real-time networks will become highly important in the future. In such a setting, particularly the timely detection of anomalies will play a significant role.

ML approaches can be roughly subdivided into the areas of supervised, unsupervised and reinforcement learning. One of the main advantages of unsupervised learning is that it is not required to manually label data sets in advance, making it particularly suitable for anomaly detection tasks. The ML models most commonly used for anomaly detection are Autoencoder Neural Networks (ANNs), which are a special type of an artificial neural network.

In this paper, we aim to combine these ingredients (real-time communication networks and ML) to provide an architecture for detection of anomalies in deterministic time through unsupervised ML in real-time Ethernet networks.

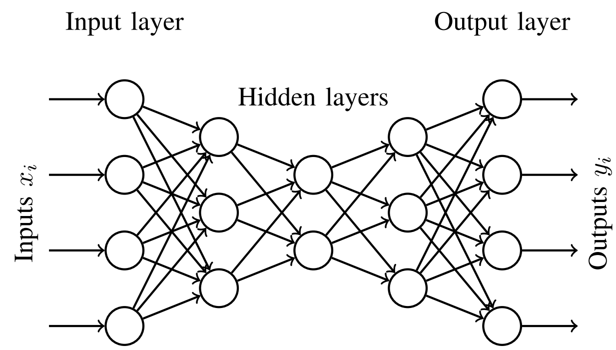

Fig. 1. Schematic overview of an ANN.

The remainder of this paper is organised as follows: Section II presents work related to this paper. The concept of an ANN is recalled in Section III. Section IV then introduces the proposed architecture and considers two use cases where this architecture can be applied. A demo implementation of one of these use cases is described in Section V. Section VI concludes the paper and gives hints to future work.

II. RELATED WORK

Zhao et al. [6] propose a network anomaly detection system based on ML. This system operates in real-time. Unlike our work, however, they do not consider a scenario in which the network itself operates in real-time. A similar approach can also be found in [4].

Work related to this paper comes from real-time networks on the one hand and from anomaly detection via ML on the other hand. The demo implementation presented in this paper is based on the scenario considered by Farthofer et al. [5], which studies redundant disjoint paths in real-time Ethernet networks.

There is a growing amount of literature which investigates the application of ML techniques to problems in the domain of communication networks, and in particular to anomaly detection. Boutaba et al. [1] hints to classical approaches for anomaly detection systems and surveys on ML approaches for anomaly detection. Casas [3] compares different ML models via their performance in the analysis of network measurements for detection of network attacks and anomaly detection. The survey in [2] investigates ML for cyber-security analytics.

III. Autoencoder Neural Networks

An ANN is a special type of a Multi-Layer Perceptron (MLP), consisting of an input layer, an output layer and several hidden layers $h_1, \ldots, h_k$ connecting them. Each hidden layer h_i consists of a certain number of neurons. In contrast to the usual structure of a MLP, in which most neurons are located in the centre of the network, an ANN becomes narrower towards the middle. Moreover, the number of outputs is equal to the number of inputs (Figure 1).

The goal of ANNs is to learn low dimensional representations of the input data $x_1, \ldots, x_n$. This is achieved by having at least one hidden layer, which has fewer neurons than the input layer. The error function is defined as

$$E = \sum_{i=1}^{n} (x_i - y_i)^2,$$

where $y_1, \ldots, y_n$ are the outputs of the ANN. Hence, the error function is a Mean Squared Error (MSE). The neural network thus learns to reproduce the inputs on the outputs. If this is achieved, the information on the thinnest hidden layer is the low dimensional representation of the input data. As we can observe, the learning process is of an unsupervised manner, which means that no labeling of the input data is required. This is an advantage, since a labeling process is usually elaborate.

An ANN can be interpreted as a composition $g \circ f$ of an encoding function f followed by a decoding function g. Here $f : \mathbb{R}^n \to \mathbb{R}^m$ is a function which computes the code $(z_1, \ldots, z_m) \in \mathbb{R}^m$ of the inputs $(x_1, \ldots, x_n)$. The function $g : \mathbb{R}^m \to \mathbb{R}^n$ restores the original vector $(x_1, \ldots, x_n)$ from this code.

The main issue with ANNs is that it is not clear a priori how many neurons are necessary in the thinnest hidden layer. On the one hand, one strives for a representation of the input data that is as low-dimensional as possible. On the other hand, the number of degrees of freedom in the input data is not known. For example, if there are indices $i \neq j$ such that x_i and x_j are uncorrelated, at least 2 neurons in the thinnest layer are necessary. This implies that one needs to figure out the number of correlations between the input data values $x_1, \ldots, x_n$. This can either be done from theoretical information of the input data (e.g., from physics, queueing theory, $\ldots$, depending on the type of data respectively use case) or in a purely experimental way. The latter can be done by performing training runs with different numbers of neurons and finally using the neural network with the lowest number of neurons that still has sufficient performance.

IV. Architecture

In this section, we propose an architecture for real-time detection of anomalies for security (intrusion detection) or safety (component failure prediction). We consider a scenario where an edge node sniffs traffic from the network. This traffic could either contain data about the network state itself (like delay values, jitter, packet loss, flow size, etc.) or data representing the state of machines/controllers connected to them. The traffic information is represented by an n-dimensional vector

$$\mathbf{x} = (x_1, \ldots, x_n) \in \mathbb{R}^n.$$

We assume that the real numbers x_i are normalised either to the unit interval or to have mean 0 and standard deviation 1. The vector $\mathbf{x}$ changes over time. Our aim is to examine these values for anomalies in the network or for hints to machines not working properly. To this end, we use an ANN at the edge node to learn low dimensional representations of the values $x_1, \ldots, x_n$. In other words, we use these values as inputs for the ANN and train it to reflect these values at the outputs. This training is done online. This means that we do not collect the data over an interval of time and train the network thereafter with the generated data set. Instead, we use the data immediately when it arrives at the edge node to update the weights and bias values of the neural network.

As outlined before, the ANN learns two functions: An encoder function $f : \mathbb{R}^n \to \mathbb{R}^m$ and a decoder function $g : \mathbb{R}^m \to \mathbb{R}^n$. The m-dimensional vector $f(x_1, \ldots, x_n)$ is the code of the input vector $\mathbf{x} = (x_1, \ldots, x_n)$. The training stops if

$$E = \sum_{i=1}^{n} (x_i - y_i)^2 < \epsilon$$

for some chosen threshold value ϵ, i.e., if the MSE is sufficiently small. Here, $y_1, \ldots, y_n$ are again the output values of the ANN. After that, the system enters a monitoring mode. In this monitoring mode, the neural network continues to be fed with the values $x_1, \ldots, x_n$. If

$$E = \sum_{i=1}^{n} (x_i - y_i)^2 \geq \delta$$

for some second fixed threshold δ (with $\delta > \epsilon$, e.g., $\delta = (r + 1)\epsilon$ for some positive integer r), it is assumed that an anomaly has been detected. Then, for example, a reconfiguration of the network can be initiated to protect the network and the devices.

The critical point is now that if all the connections in the network are real-time connections, then the detection of anomalies will be real-time as well. This is due to the fact that the computation of the output values of neural networks consists exclusively of a fixed number of additions, multiplications and applications of activation functions. Hence this can be done in deterministic time as well. Moreover, in suitable systems, also the reaction to an anomaly may be done in deterministic time. This then provides a closed deterministic anomaly detection end-to-end loop. In the following, we provide two use cases for this architecture:

A. Use Case 1

An edge-node collects information from various devices in a communication network based on real-time Ethernet (see Figure 2). We assume that all nodes in this network operate

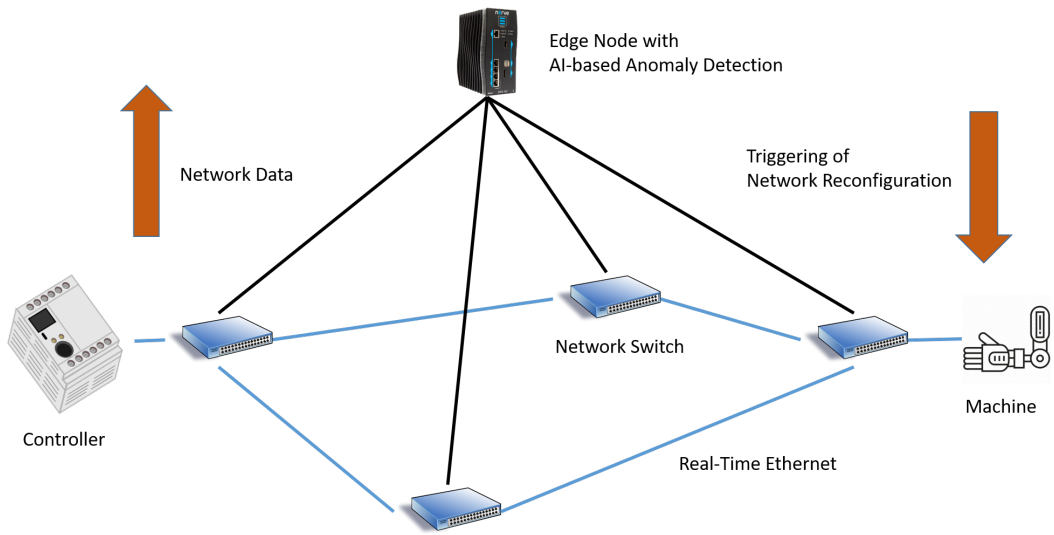

Fig. 2. Use Case 1: Anomaly detection of network data and real-time reconfiguration of the real-time Ethernet network

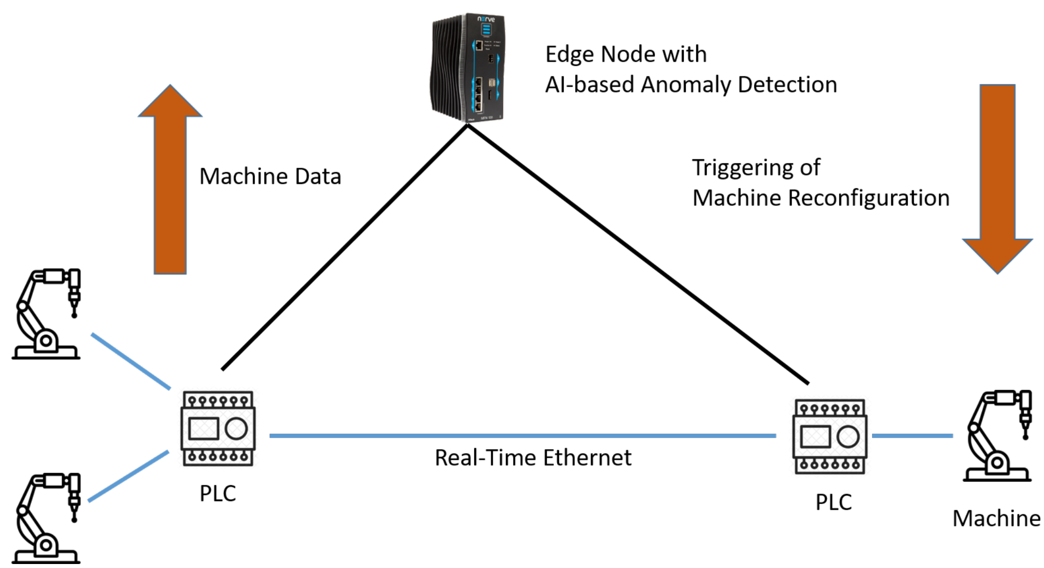

Fig. 3. Use Case 2: Anomaly detection of machine data and real-time reconfiguration of the industrial machines (network switches not explicitly shown in this figure)

in real-time as well. The network data may consist of delay values, jitter, traffic load and number or configurations of flows. The information is represented by an n-dimensional vector $\mathbf{x} = (x_1, \ldots, x_n) \in \mathbb{R}^n$, which changes over time. An anomaly detection system based on an ANN at the edge-node is fed with the vector $\mathbf{x}$. As soon as an anomaly is detected, the edge-node could trigger building blocks based on Software Defined Networking (SDN) to reconfigure the network configuration. As an example, a flow, which uses a certain path p_1, could be reconfigured to use a path p_2 after an anomaly has been detected to circumnavigate an issue or attacker.

B. *Use Case 2*

In this use case, sensor values $x_1, \ldots, x_n$ of machines are sent over a real-time network to the edge node (see Figure 3). At the edge node, an ANN is trained online to reproduce the sensor values. A detected anomaly may for example indicate a machine error. And a quick detection and analysis in deterministic time could prevent damages to the involved machines or products within a previously specified reaction time.

V. Proof of concept Implementation

A proof of concept implementation of the proposed architecture was realised in our laboratory (see Figure 4).

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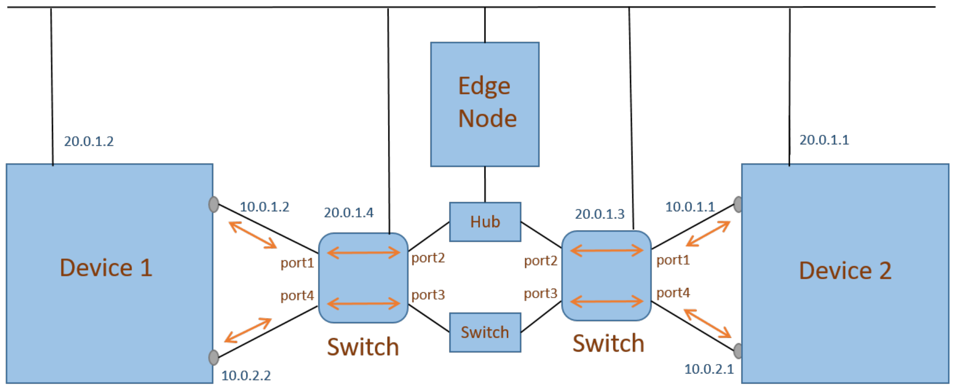

Fig. 4. Schematic overview of the realized proof of concept setup

Two real-time communication capable devices (representing controllers or machines) are connected through a real-time Ethernet network. To be able to demonstrate various scenarios, including for example fast failover, the devices are connected via two disjoint paths. In a separate network, an edge node running the ML algorithms (in our case the ANN) is connected to the network switches and devices to trigger network or controller/machine reconfigurations. Finally, the edge node is also directly connected to the real-time Ethernet network so it can mirror and listen into any communication between the two devices. For a demonstration, we simulated machine sensor/network information values by generating random real numbers $a_1, \ldots, a_m$ uniformly distributed in the interval $[0, 1]$ and by generating input values $x_1, \ldots, x_n$ of the form

$$(x_1, \ldots, x_n)^t = A \cdot (a_1^2, \ldots, a_m^2)^t + B \cdot (a_1, \ldots, a_m)^t + \mathbf{c}$$

Here $A, B \in \mathbb{R}^{n \times m}$ are randomly generated (but fixed) matrices and $\mathbf{c} \in \mathbb{R}^n$ is a fixed random column vector. This simulates the number of correlations between the values $x_1, \ldots, x_n$. Note that we thereby know the number of degrees of freedom, which is exactly equal to m. This number corresponds to the number of neurons needed in the thinnest layer of the neural network.

The neural network was implemented in Python, using the TensorFlow framework. We used a scenario with 16 network status information values $x_1, \ldots, x_{16}$. The number of degrees of freedom was set to 8. They were all normalised to have mean values 0 and standard deviation 1. The ANN consisted of 3 hidden layers, with 12 neurons in the first hidden layer, 8 neurons in the middle hidden layer and 12 neurons in the third hidden layer. The ANN achieved a performance of an MSE of 0.01 after an online training with $\approx 10^4$ generated samples $x_1, \ldots, x_{16}$. This MSE multiplied with 3 was then used for the monitoring mode as the offset value for the detection of an anomaly.

After an anomaly is detected by our ANN, a reconfiguration of network flows (e.g., shutting down a network path, switching to another network path) or a reconfiguration of the machines (e.g., new parameter settings) are triggered. This thus closes our deterministic anomaly detection loop, since all components operate in deterministic time.

VI. Conclusion and Future Work

We proposed an architecture for an end-to-end deterministic anomaly detection system in real-time networks. This is achieved via an online training of an ANN at an edge node. We provided two use cases where this architecture may be applied. We implemented the architecture in one of these use cases as a demo implementation, and thus delivered a proof-of-concept. In the future, measurements will be performed to evaluate the proposed architecture in terms of the actual reaction time from anomaly detection to network or machine reconfiguration. The results will then be compared to measurements in existing anomaly detection systems.

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