Smart Home Techniques for Young People with Functional Disabilities

Daniel Einarson
Department of Computer Science
Kristianstad University
Kristianstad, Sweden
e-mail: daniel.einarson@hkr.se

Marijana Teljega
Department of Computer Science
Kristianstad University
Kristianstad, Sweden
e-mail: marijana.teljega@hkr.se

***Abstract*—A purpose behind the United Nation's Agenda 2030 is that no one shall be left behind, which implies that support for vulnerable people shall be seen as clearly significant. In that context, assistive technologies serve purposes of improving disabled individuals' inclusiveness and overall well-being. This contribution covers ongoing experiments on techniques developed for Smart Homes, where the outcomes of such developments are targeted towards young people with functional disabilities, in order to provide them with independence in their own living space.**

Keywords - Smart Homes; IT-based support systems; Sustainable Development; Quality of Life; Assistive technologies.

I. INTRODUCTION

The expression 'leave no one behind' is a cornerstone of United Nation's (UN) Agenda 2030, so that even the most vulnerable people are guaranteed an acceptable level of quality of life. Matters of *leaving no one behind* are covered in a discussion paper of the United Nation Development Program (UNDP). Here, several key factors and the meaning behind those are discussed, such as *discrimination*, based on, for instance, *age, social class and disability* [1]. To be even more precise, the *disability* aspect is further elaborated on through several of the Agenda 2030's Sustainable Development Goals, their targets, and indicators [2]. Here, for instance, target 4.5 relates to appropriate access to education, 10.2 relates to reduced inequalities with respect to income, and 16.7 relates to societal inclusiveness, all with perspective in the situations of disabled people.

The Convention on the Rights of Persons with Disabilities (CRPD) is intended as an instrument to achieve human rights for disabled people concerning a multitude of aspects, such as, making their own free decisions in their lives and being active members of society. To meet that, the necessity of research on, and development of, assistive technologies, as well as the availability of those, is proclaimed [3]. Furthermore, through the program *Global Cooperation on Assistive Technology* [4], the World Health Organization (WHO) points out that not only is assistive technology a tool to ensure quality of life for disabled people, but also, such technology shall be a human right. In that context, Information Technology (IT), as an example of a technology, has a rather minor role in the context of sustainable development, and has been more seen as a complementary tool [5]. Still, IT has also been claimed to be a driving force in contexts of *quality of life* [6].

At the Department of Computer Science, Kristianstad University, Sweden, there have been ongoing experiments during several years, with specific focus on developing IT-based support systems for people with functional disabilities. Especially, focus has been on younger students at specific secondary schools, with support for an independent living for those students. Thus, the context of Smart Home-techniques has been especially emphasized, where the experiments have been conducted as research projects, as well as served as examples of project-based teaching and learning Computer Science courses material. At the core of the work stand the questions on how to develop techniques, and arrange techniques to support differently-abled persons in their daily living. This, in turn, should have consequences on grades of societal inclusiveness, as pointed out by high level actions, such as, UN's Agenda 2030, CRPD, and WHO's Global Cooperation on Assistive Technology.

This contribution will cover IT-based techniques experimented on prototype systems. Such systems and techniques especially address assistance in the daily living of young people with functional disabilities, and, thus, should contribute to the quality and the sustainability aspects of life for those people.

The contribution is outlined as follows: Section II will provide a description of the case, while Section III will discuss related work. Section IV will give a brief overview of the methods of use, and the results of the work will be presented in Section V, Section VI, Section VII, and Section VIII. Section IX will provide discussions on the work, and, finally, Section X will present conclusions and further work.

II. DESCRIPTION OF THE CASE

Riksgymnasiet is a secondary school in Sweden for students aged 16 to 19 years old who have different kinds of functional disabilities. Sweden has four such schools, where one of those is positioned in Kristianstad, in the very south of Sweden. The students may come from different parts in Sweden and have accommodations arranged close to the school.

In 2012, a study was performed by researchers at Computer Science, Kristianstad University (CS@HKR), at Riksgymnasiet at Kristianstad, with the purpose of investigating possible IT-based support systems to be used by students in their daily living at that school. In parallel with that study, a prototype system was developed, where the end users (i.e., students at Riksgymnasiet) were able to turn on and off the light of lamps from apps developed for smart phones in their rooms [7]. The studies showed that the end users (as well as support staff at Riksgymnasiet), were satisfied with the prototype system, and that they also had further desires from such a system. For instance, they wanted to have support for different kinds of practical activities that, at that time, needed a personal assistant's cooperation.

Among other things, researchers at CS@HKR observed that it was impossible for the students to pull down blinds, and put on fans by themselves to protect themselves from the sunshine and heat in their rooms. Furthermore, the air quality was questionable and could gain from being controlled. Such conclusions formed the basis for further investigations and technical development of a support system, in order to increase the degree of independence of the end users' accommodation. Apps, as well as other user units, should be developed to control devices in the homes. While several solutions exist today for Smart Home-techniques for use by the common public, it should be noticed that it is also especially important to regard the diversity of the end users' needs.

III. RELATED WORK

There exist several examples of academic approaches to Smart-Home systems for people in home settings (for instance, the *Home Aware Research Initiative* at Georgia Tech, [8], and Washington State University's initiative, *Integrative Training in Health-Assistive Smart Environments*, [9]). The work of this specific contribution is especially motivated by, on one hand, the possible applicability of the emerging flora of new techniques, and, on the other hand, by the end-users' need for participatory customization to meet a diversity of needs.

Today, there are several examples of commercialized Smart Home-systems for the common public, such as to control lamps and washing machines remotely through the use of apps. Often, those are not integrated as one in the same system, even though, for instance, *Apple* provides large scale solutions in that direction. Still, in contexts of diversity in disabilities, requirements of integrating off-the-shelf components with customized solutions may be hard to overcome.

The result of the Brundtland's commission [10] has provided a view on sustainable development that today is widely acknowledged. First, that view concerns not only environmental aspects, but also economic and social aspects. Second, as a temporal dimension, sustainable development concerns the sustainability of today, as well as of tomorrow (or, more precisely, meeting today's needs, without compromising the needs of tomorrow).

Seen from a sustainability perspective, commercial products certainly correspond well to economic aspects. Projects, as covered in this contribution, developed for Smart Homes to support people with specific needs, and, thus, in the context of assistive technologies, typically relate to social aspects of sustainable development. Research at CS@HKR indicates experiences from the development of several systems in the domain of eHealth to provide support for people with specific needs. Hence, investigations especially point out social aspects on sustainable development. Examples of these include:

- Internet of Things-based support systems for parents with Attention Deficit Hyperactivity Disorder (ADHD) and Autism [11], where prototype systems were developed, for instance, to remind the parents of things to carry with them when leaving their home, through tagging the things and matching that against a 'remember map'.
- Food supply systems for elderly people [12], where, among other things, a Smart Phone app was developed to filter in and filter out food choices of the day, based on e.g., nutrition aspects and allergies.
- Support systems for people with cognitive disorders [13]. Prototypes were developed to support children with a communication support for them to move freely outdoors.

Studies behind these examples have been performed on the bases of participatory action research [13], tested on potential end-users [12], and with careful investigations of the daily living of stakeholders [11]. However, the above examples are typically time-limited research projects, that is, with no sustainability in time and with a need for further follow up strategies.

It can clearly be seen that 'following up' needs to take place at several meetings for feedback-information from the end users. Especially, disabilities may also mean diversity and, therefore, a need for customizing solutions. The question of what matters to people is presented by Greenhalgh et al. [14] and, putting that work in the context of this contribution would mean that 'following up' would put focus on the needs of the end users as a driver for the technical solutions. In that context, the observation that *science of assisted living is still in its infancy* is especially interesting and certainly needs more attention.

Meurer et al. [5] take a conceptual approach to the sustainability of the design of IT-based projects for support for the continuing living for elderly at home. Here, among other things, sustainability relates to a temporal scale and the approach problematizes around the typical time limits that apply to research-related projects. In the context of [5], a sustainable development shall be seen on the basis of a multidimensional space, with aspects, such as, outcomes at *levels of individuals*, and implications at *levels of organizations*. Here, it is claimed that the effect of developing a research project tends to end when a project is over, and, thus, will not correspond to a sustainable development.

IV. METHODS

While early initiatives were taken to understand the living situation of the young students at Riksgymnasiet, later experiments were mainly done at the lab at CS@HKR. Here, development processes have typically been prototype-based, which is an efficient way of testing out ideas, reject ideas, and build new solutions upon previous successful experimentations.

V. SYSTEM DESCRIPTION

A system overview is captured by Figure 1, illustrating the main system architectural parts. The *User Controlled Units* correspond to the communication from end user's point of view (such as apps), while the *Home Devices* correspond to devices to be controlled (such as lamps). Communication flows wirelessly (typically based on techniques such as Bluetooth and Wi-Fi) through a server and a database with information regarding current user units and home devices.

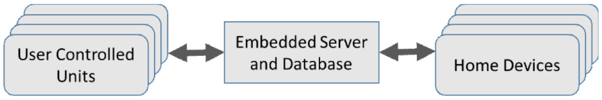

Figure 1. Smart Home system overview.

In the sequel, user units, home devices, and the usability of those, will be described in more detail. Techniques have been experimented on, and developed by, researchers and by students at CS@HKR under the researchers' supervision.

VI. USER CONTROLLED UNITS

Different kinds of user units have been developed to be able to control the system, as outlined in Figure 2. The use of those will be further described in this section.

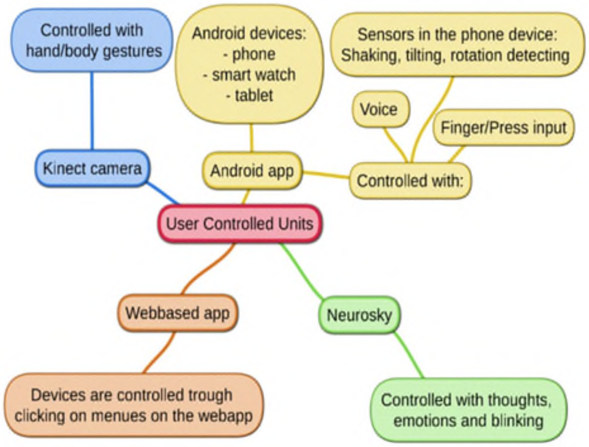

Figure 2. User Unit overview.

A. *Smart Phone Apps*

Apps for Smart Phones have been especially developed based on Google's Android platform. The apps have been developed to control Smart Home-devices through pushing buttons on common user interfaces, such as illustrated in Figure 3. Their use at Riksgymnasiet, as shown by experiments done there [7], was regarded as quite 'cool' by the end users. Still, even though the interaction form in itself is common today, the usability is a challenge that needs to be addressed. This concerns both the clarity of the details of the user interface as well as usefulness in cases of different grades of functional disabilities.

To open up for further possibilities, voice recognition has also been introduced. For instance, the spoken command '*Turn on the light'*, implies an answer from the Smart Home, '*I heard you said turn on light*', followed by the light being turned on. Experiments like this have been performed in order to provide a variety of forms of communication, based on a diversity of needs. Yet, another example is based on the use of sensors of a Smart Phone when shaking and rotating it. The three-axials accelerometer of Android phones corresponds to a 3D space, to compute and form different commands.

Figure 3. Smart Phone User Interface example.

B. *Camera based interfaces for capturing gestures*

Preliminary gesture languages have been developed where the gestures are captured by a Kinect camera [15] and interpreted through software especially developed to recognize the different language elements. Even though the Kinect camera originally was developed for computer gaming reasons, it can be used generally to notice movements in a 3D space, see Figure 4.

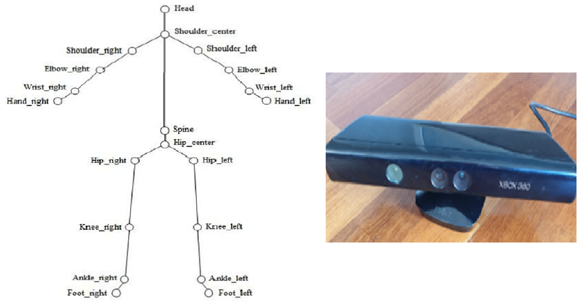

Figure 4. Detection of skeleton joints (skeleton picture from [16]).

Here, the camera has been used to notice simple up-down or left-right hand movements to control lights, fans, or a curtain. The technique records each joint on the body/skeleton to represent 3D coordinates *(x, y, z)*, which, then are further converted to commands. There are 20 joints for one person, can be used to interpret more complex gesture recognition commands [17].

The joint detection was done with the camera's depth image information. To map each one of them is a complex work, where each one is composed of 3D coordinates; for example, the right-hand 3D coordinates are: *(x1, y1, z1)*, *(x2, y2, z2)*, *(x3, y3, z3)*.

C. *The NeuroSky brainwave interface*

To meet even harder degrees of disabilities, experiments have been introduced with NeuroSky brainwave headsets, see Figure 5. The control of home devices is triggered by thoughts, emotions and blinking. One experiment was done with different combinations of specifically chosen thoughts to form commands that can be used to control the window curtain. The result was showing that a combination of two specific thought tasks could be used to form two commands with 97% accuracy performance, and that three specific thought tasks could form three commands with 92% accuracy performance [18].

Figure 5. The NeuroSky BrainWave Headset.

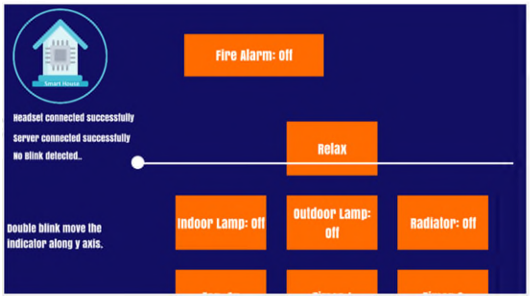
Headset connected successfully
Server connected successfully
No Blink detected..
Double blink move the indicator along y axis.

Figure 6. A NeuroSky controlled menu.

The experiment showed that the strongest two thought tasks are when a person is counting backwards, and the second one is when a person is imagining and focusing on the point between the ears in the head. It was suggested to continue with this experiment by using eye blinking to build several more commands.

Another experiment on the NeuroSky headset was the use of relaxing modes to move an indicator along the y-axis, which gets a user into a desired part of a menu. Well inside the menu, the user can choose to blink once to turn on or off the chosen device (for example the lamp) or blink twice to continue moving inside the menu, as illustrated in Figure 6, and exemplified by students at CS@HKR through a short video-clip [19].

D. *Web-based interface*

Although the previously presented user-side units of a possible Smart Home can provide good opportunities to control the home's devices, the information about the state of the home is rather limited. Through a web-based user interface, not only more detailed information is provided, but also additional practical possibilities to control Smart Home devices. Figure 7 illustrates that devices, such as lamps, fans, and blinds in several different rooms may be controlled from a web-based user interface. Furthermore, Figure 7 shows that additional information about, for example, air quality (temperature, humidity, carbon dioxide, etc.) can be summarized by a more complete interface.

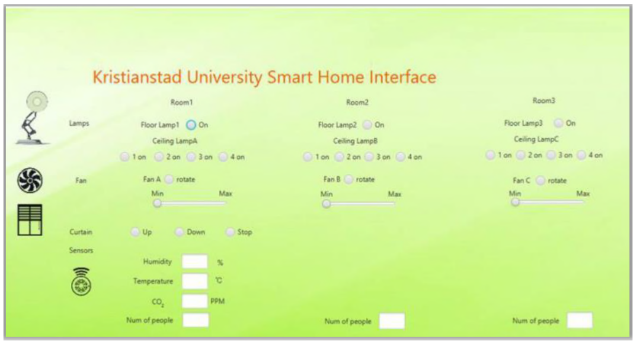

Figure 7. A web-based user interface.

The scale of a web-based user interface is not only beneficial for additional usability for an end-user (if this is useful to the user in terms of their capabilities), it also provides opportunities for supporting organizations to communicate with the Smart Home remotely. That is, a person with special needs can receive support remotely and, therefore, this can contribute to being independent of the physical presence of personal assistants. Such insights also indicate many additional opportunities in the development of IT-based support for Smart Homes.

VII. HOME DEVICES

While the previous section on user units mainly presented the 'left part' of the system, as outlined in Figure 1, the 'right part' corresponds to the devices of the Smart Home, that is, things to be observed or manipulated. For experimentation reasons, both for research and for examples in student projects, real as well as simulated devices have been used.

The actions of devices are mainly triggered through user commands, but, in some cases, activities are triggered by inbuilt intelligence. Examples on this include a fan that is turned on when the temperature exceeds a certain level.

A. Real devices

Real devices correspond to devices that may be used in common homes, see Figure 8. This includes, for instance, lamps or fans from IKEA (as is also the case in the experiments performed). Adapters have been used here to convert from high- to low level voltages. Furthermore, blinds have been fitted with a machinery to be able to be lifted up and down remotely.

At the endpoints of the devices (lamps, fans, etc.), microprocessors have been attached, which furthermore have been programmed to fulfill the specific tasks of controlling the devices (turning on, pulling down, etc.). The microprocessors, in turn, carry communication devices for remote communication based on, e.g., Bluetooth or Wi-Fi.

Figure 8. Examples on physical devices. Pictures from lab and from [20].

Furthermore, sensors have been used for detection of quality of air, based on humidity, temperature, and carbon dioxide. Moreover, sensors based on ultrasonic sound have been experimented on to catch the number of entrances and exits in and out of a room.

B. Simulated devices

For experimentation reasons, a small scaled model of a house has been used by students, as shown in Figure 9. From the point of view of techniques for a Smart Home, this house still has a wide range of functionalities that, in several cases, may be scaled up into real life contexts. Table 1 provides an overview of those.

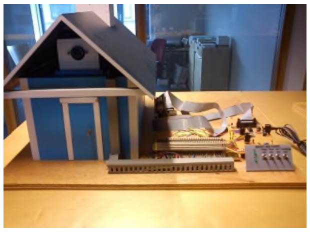

Figure 9. A small scaled model of a house.

TABLE I. FUNCTIONALITIES IN A SMART HOME

	Functionality	***Description***
1	Automatic fire alarm	This signal is simulated with a switch
2	Housebreaking alarm	This input is realized by using a magnetic switch mounted at the house door
3	Water leakage alarm	This signal is simulated with a switch
4	Temperature indoors	This signal is realized using an analog temperature sensor mounted inside the house (on the first and the second floor
5	Temperature outdoors	This signal is realized using a digital temperature sensor mounted outside the house
6	Stove On	This signal is simulated with a switch on the front panel
7	Window open	This signal is simulated with a switch
8	2 Timers	This output signal is simulated with an LED lamp on the front panel
9	Lighting indoors	This function is realized with a lamp mounted inside the house
10	Lighting outdoors	This function is realized with a lamp mounted outside the house
11	Power cut	This input is realized by controlling the presence of supply voltage
12	Electricity consumption	This input is realized by measuring the supply voltage deliver to the house (an analog signal)
13	Twillight automatic system	This input is realized by Light-to-Voltage sensor (outdoors)
14	Fan	This function is realized with a fan mounted on the house's loft
15	Radiator	Four power resistors are connected in series to realize the heating of the house. The resistors are mounted in pairs, two at each long side wall

From Table 1, some functionalities are merely simulated by switches at a processor board (such as, *Window open*), while others have potentials to be connected to a prototype system. For instance, *Lighting indoors* may be manipulated through a smart phone-app, and *Temperature indoors*, may be used to trigger actions of *Fan*, and *Radiator*.

VIII. FURTHER INVESTIGATIONS

Several concepts have been experimented on, in addition to the above-mentioned techniques. Those increase the potential for a possible full-scaled development of Smart Home-support systems. Here, system development has typically been done through student projects, and student thesis work at CS@HKR. Examples include:

- Usability aspects of Smart Phone User Interfaces (UI). The UI not only have to be attractive in their shape, but, e.g., must also meet the complexities of a possible growing number of devices of a Smart Home.
- Scheduling Smart Home-functionalities, where events can be activated through time points set at, e.g., Google Calendar.
- Security aspects of Smart Homes, which, of course, constitute a fundamental matter to protect the individuals' integrity.

- Spatial awareness, that is, a system's awareness of where the users, as well as devices, are positioned in a Smart Home
- Simulations of devices, such as Media players, and Microwave ovens.

The core purpose of the techniques presented in this contribution has a focus on the independence of the living of the end users, that is, in our case, young people with different kinds of functional disabilities. Although the projects listed above and in previous sections show promising results so far, they need to be critically examined from several perspectives.

With a diversity of disabilities, supporting techniques certainly must be customized to suit specific needs. Moreover, the degrees of independence a system contributes with must be examined, based on a conceptualized framework. For instance, a fan may be controlled from a distance through an app and, therefore, provide a significant degree of value, while controlling a washing machine from an app may bring less value, since it still must be loaded with clothes. Here, concepts should relate to the degree of independence and the degree of external assistance that is still needed even with the support of the developed system.

IX. DISCUSSIONS

High level organizations, such as UN and WHO, have stated ambitions concerning especially vulnerable people, where it is pointed out that *no one shall be left behind*. Furthermore, actions such as *Agenda 2030* and *Global Cooperation on Assistive Technology*, addresses the situation of disabled people, where the quality of life of those people and their societal inclusiveness are especially emphasized.

As research and development organizations, academia certainly has a role to play here, where, on one hand, the situations and specific needs of the disabled people should be studied and concretized, and, on the other hand, solutions should be found and developed. Moreover, bridging a gap between need and solution can probably only be done through participatory research, that is, research where representatives of the end-users act cooperatively with researchers and developers, and only then.

This contribution has had a starting point in observations of the living situation of young students at Riksgymnasiet in Kristianstad, Sweden. The technical prototypes that have been developed from that starting point have yet only been executed in lab environments. Still, this has brought a level of maturity of the techniques and skills in handling those, which may contribute well to possible future participatory research projects.

Several examples on technical solutions have been tested out and put into contexts of complete Smart Home prototype systems. Different kinds of user-controlled units are used here to observe or manipulate different kinds of home devices. Even though prototypes may be stable at preliminary levels, putting those in real world contexts certainly will require several exhaustive test cases. Still, so far, the work seems to show clear potential in serving as an example of a useful assistive technology.

X. CONCLUSIONS AND FURTHER WORK

This contribution has presented experiments that have been ongoing over several years regarding the development of IT-based solutions to support people (especially young people) with functional disabilities in their housing, through technologies for Smart Home. User units for a variety of disabilities have been developed and prototyped together with devices related to Smart Homes. The state of the prototypes is mostly at the level of labs, that is, they need to be further tested out in contexts they are intended to be used, that is, the housings of disabled people.

In addition, the development of such prototype systems has been discussed in the context of sustainable development. This has partly been done with respect to Agenda 2030 and especially on a level of usefulness for the individuals. For the individuals, sustainability especially corresponds to how well the outcome of projects may work over time. Further work needs studies of the core technical aspects, as well as the usefulness of the end user-related aspects.

The covered techniques and the systems/subsystems need in many cases be further investigated for the sake of achieving a mature and trustworthy level. From a system perspective, several qualities must be especially studied, such as, robustness, performance, and security. Still, such qualities may solely relate to sustainability from a perspective of the system in itself.

For the sake of sustainability in use, an iterative process involving end users and support organizations for collaboration and participation must be further initiated. Initiatives for further collaboration between researchers at CS@HKR and the Riksgymnasiet have been taken, and a mutual interest in future collaborations has been shown. A form of such collaborations should also emphasize a conceptualization of grades of independence that technical support may provide. Solutions should be useful for purposes of independence in the daily living, not only motivated by the functionality of the technique itself.

ACKNOWLEDGMENT

Acknowledgments to the students and staff at Riksgymnasiet who were involved in and have contributed to the first studies behind this contribution. Also, many thanks to all the students over the years who have contributed with experiments and system development in project-based courses and thesis work in the study programs in Computer Science at Kristianstad University.

REFERENCES

[1] S. Renner, L. Bok, N. Igloi and N. Linou, “What does it mean to leave no one behind?” A UNDP discussion paper and framework for implementation, 2018.

[2] United Nations Statistics Division, “SDG Indicators” Availabe from: https://unstats.un.org/sdgs/metadata/ 2020.02.23.

[3] United Nations Convention on the Rights of Persons with Disabilities, “United Nations Convention on the Rights of Persons with Disabilities,” 2006, Article available from: https://www.un.org/development/desa/disabilities/convention-on-the-rights-of-persons-with-disabilities.html 2020.02.23.

[4] Global Cooperation on Assistive Technology, “Disability and rehabilitation,”World Health Organization, Available from: https://www.who.int/disabilities/technology/gate/en/ 2020.02.23.

[5] J. Meurer, C. Müller, C. Simone, I. Wagner and V. Wulf, “Designing for Sustainability: Key Issues of ICT Projects for Ageing at Home”, Computer Supported Cooperative Work (CSCW), 27, pp. 495–537, 2018.

[6] D. Hornung, C. Müller, I. Shklovski, T. Jakobi and V. Wulf, “Navigating Relationships and Boundaries: Concerns around ICT-uptake for Elderly People”, Technology Use Challenges for Older Adults, CHI-2017, Denver USA, 2017.

[7] Z. Demant, “Interaktivt hus”, Bachelor Thesis in Computer Science, Kristianstad University (in Swedish), 2012.

[8] J. A. Kientz et al., “The Georgia Tech Aware Home”, Research Landscapes , CHI-2008, Florence, Italy, 2008.

[9] Washington State University, “Integrative Training in Health-Assistive Smart Environments”, Availabe from: http://igert.eecs.wsu.edu/index.html/ 2020.02.23.

[10] G. H. Brundtland, “Our Common Future: The World Commission on Environment and Development”. Oxford: Oxford University Press, 1987.

[11] D. Einarson, P. Sommarlund and F. Segerström, “IoT-Support Systems for Parents with ADHD and Autism”, International Conference on Computational Systems & Information Technology for sustainable Solution, csitss, 2016.

[12] D. Einarson and D. Saplacan, “The Active Ageing Approach to Quality of Life for Elderly People through Order and Distribution Chains”, International Conference on Computational Systems & Information Technology for sustainable Solution, csitss2016, 2016.

[13] D. Saplacan and D. Einarson, "A Participatory Action Research Approach to Developing Assistive Technologies for People Suffering from Cognitive Disorders," in Living Knowledge Conference, Copenhagen, 2014.

[14] T. Greenhalgh et al., “What matters to older people with assisted living needs? A phenomenological analysis of the use and non-use of telehealth and telecare”, Social Science & Medicine, 93, pp. 86-94, 2013.

[15] D. Levac, D. Espy, E. Fox, S Pradhan and J. E. Deutch, “"Kinect-ing" With Clinicians: A Knowledge Translation Resource to Support Decision Making About Video Game Use in Rehabilitation”, Innovative Technologies Special Series, Physical therapy, Volume 95, Number 3, pp. 426-440, 2015.

[16] A. Shingade and A. Ghotkar, “Animation of 3D Human Model Using Markerless Motion Capture Applied To Sports”, International Journal of Computer Graphics & Animation (IJCGA), Vol.4, No.1, pp. 27-39, 2014.

[17] L. Huynh et al. “Robust classification of human actions from 3D data”, 2012 IEEE International Symposium on Signal Processing and Information Technology, San Juan, PR, USA, pp. 263-268, 2012.

[18] M. Teljega, “Automatic control of a window blind using EEG signals”, Master thesis of Science in Computer Science with specialization in Embedded Systems, Kristianstad University, 2018.

[19] S. Dehghani, E Haol, A. Abdulal and N. Cunha, “The art of turning on the light with the power of the mind”, Kristianstad University News, in Swedish, Available from: https://www.hkr.se/nyheter/2020/konsten-att-tanda-en-lampa-med-tankens-kraft, 2020.02.23.

[20] The Application of PWM Capture (Data Acquisition) and Ultrasonic Sensors, Aimagin blog, Available from http://aimagin.com/blog/pwm-capture-data-acquisition-and-ultrasonic-sensor, 2020.03.25.