Empowering Persons with Deafblindness: Designing an Intelligent Assistive Wearable in the SUITCEYES Project

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ABSTRACT

Deafblindness is a condition that limits communication capabilities primarily to the haptic channel. In the EU-funded project SUITCEYES we design a system which allows haptic and thermal communication via soft interfaces and textiles. Based on user needs and informed by disability studies, we combine elements from smart textiles, sensors, semantic technologies, image processing, face and object recognition, machine learning, affective computing, and gamification. In this work, we present the underlying concepts and the overall design vision of the resulting assistive smart wearable.

CCS Concepts

• **Human-centered computing~Empirical studies in HCI**
• **Human-centered computing~Collaborative and social computing devices** • *Human-centered computing~User studies*
• *Human-centered computing~Empirical studies in interaction design* • *Human-centered computing~Accessibility theory, concepts and paradigms* • *Human-centered computing~Accessibility systems and tools* • **Social and professional topics~History of hardware** • **Social and professional topics~Codes of ethics** • **Social and professional topics~Assistive technologies** • **Computing methodologies~Cognitive robotics**
• **Computing methodologies~Robotic planning** • *Applied computing~Consumer health*

Keywords

Deafblindness; Assistive Technologies; Haptics; Smart Textiles; Wearables; Visual Impairments; Hearing Impairment; Gamification.

1. INTRODUCTION

Innovations in information and communication technology improve the quality of life for many people. However, most solutions rely on vision and sound. Thus, they often exclude people with severe dual vision and hearing impairments. Deafblindness is such a condition, limiting communication primarily to the haptic channel (Figure 1).

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Figure 1: There are about 2.5 million people with deafblindness in Europe. [Image courtesy of LightHouse for the Blind and Visually Impaired, see <http://lighthouse-sf.org>.]

This entails multiple challenges at different levels for a wide range of people, from individuals with deafblindness to society as a whole. At the individual level, a person with deafblindness is typically reliant on other people with limited autonomy as a result. However, there is an enormous amount of stimuli in the environment consciously or unconsciously observed and absorbed by a person who can see and hear. In comparison, the information communicated to a person with deafblindness is only a very limited select fragment.

At a societal level, we often heard about the costs involved due to the required human interventions. However, the contributions of this community, missed due to the lack of adequate inclusion measures in our social structures, are an even greater loss. We need to improve the accessibility of the environment for all people, regardless of their background or abilities.

Though rare at birth, deafblindness can be acquired due to different causes. Currently an estimated 2.5 million people with deafblindness are living in the Europe. Due to the increasing life expectancy and the aging population, this number is forecasted to rise substantially by 2030. The members of the EU-funded project SUITCEYES acknowledge that changes in society are needed to address these challenges. At the same time the project takes first steps towards this objective: European policy developments are evaluated to improve accessibility and inclusion. The results of these analyses will inform and guide the development of the project's technical solution.

Figure 2: Network visualization of keyword co-occurrences of 809 publications using the data analysis tool VOSviewer.

In SUITCEYES three main challenges of users with deafblindness are addressed:

- perception of the environment;
- communication and exchange of semantic content;
- learning and joyful life experiences.

As limited communication is the predominant problem, state of the art technologies will be explored and a haptic communication interface will be developed to enable an improved context-aware mode of communication. We aim to extract environmental and linguistic clues and translate them into haptic and thermal signals that will be communicated to the user via a “haptic intelligent, personalized, interface” (HIPI).

In the SUITCEYES project, we are combining elements from smart textiles, sensors, semantic technologies, image processing, face and object recognition, machine learning, affective computing, and gamification in order to develop a novel mode of communication. Such technology-driven innovations are often welcomed by people with deafblindness and disabilities due to the independence they can offer. However, in many cases they remain unused and discarded [1] for two main reasons:

1. The development may not take into account the needs and preferences of the users, for example by overemphasizing the priorities of professionals. To address this, people with deafblindness are involved in the project as advisors at all stages.
2. Policies may fail to promote access. Although most countries signed both the UN Convention on the Rights of Persons with Disabilities [2] and the European Accessibility Act is already under development, knowledge of technological possibilities remains restricted. The project addresses such aspects of environmental accessibility by linking technological developments to national and international policy and practice on accessibility.

Designed based on expressed needs and preferences of the users, the HIPI-system will afford new means of perceiving the environment as well as user-triggered communications. This in turn allows the users to take a more active part in society, improving possibilities for inclusion in social life and employment. In addition, learning experiences will be enriched by gamification and mediated social interactions. While the scope of the project is broader, the focus of this paper is to present the outline for the technical solution proposed in the project.

2. DEAFBLINDNESS

A definition of deafblindness is provided by the Nordic Welfare Center [3] as “a combined vision and hearing impairment of such severity that it is hard for the impaired senses to compensate for each other. Thus, deafblindness is a distinct disability.” The severity of the condition can vary. At one end of the spectrum there are profound impairments in both visual and hearing senses, at the other end, a slight sight or hearing may remain. Variations in conditions can also stem from the causes of deafblindness. Deafblindness can be congenital or acquired through accident, illness, or age. Furthermore, deafblindness can be accompanied with various levels of physical and or cognitive abilities. Figure 3 provides an overview of their different levels. The aim of the project is to improve perception, communication and quality of life for people with deafblindness.

Research on deafblindness and related issues remains limited. As of February 2018, only 809 scholarly publications on deafblindness could be found on the Web of Science database – in contrast to almost 400,000 items on blindness in the same database. Of the publications on deafblindness, only 23 were to some degree related to ‘haptic’, and of those only a handful related to what is proposed in the SUITCEYES project (Figure 2).

Figure 3: Deafblindness: causes and cognitive impact. SUITCEYES challenges and expected impact areas.

Even research on the life and behavior of people with deafblindness is scarce. In 2016 and 2017 two comprehensive Swedish dissertations (deemed to be the first in the world) were published focusing on people with Alström's syndrome [4] and with Usher's syndrome [5]. In both cases, the researchers identified constant pressures that lead to experiences of overwhelming exhaustion. The number of people that a person with deafblindness can communicate with and trust is very limited, not to speak of diminished possibilities in finding jobs, earning money, or leading an independent life.

The cumulative effects of such difficulties are manifold and varying, including high levels of depression, suicidal thoughts and behavior, diminished life quality, worsening of cognitive abilities and development of neurological disorders. Those researchers found that the most fundamental problem is interaction with surroundings and communication with other people.

In 2015, the Journal of Deafblind Studies on Communication [6] was established by the University of Groningen. In the last three years, only 13 articles have been published there. SUITCEYES addresses some of the communication challenges identified in earlier researches, and recognizes that facilitating communication for people with deafblindness reduces levels of stress and is crucial for improvements in the quality of their life and health. Furthermore, the solution developed within SUITCEYES will be of help to family members and professional caregivers, facilitating their work and enabling it to become more efficient and effective.

3. SOLUTION DESIGN

The overall objective of SUITCEYES is to improve the level of independence and participation of people with deafblindness. Together with experts, caretakers and future users, we aim to augment communication, perception of the environment, knowledge acquisition and the conduct of daily routines.

As introduced in section 1, our proposed solution is a haptic intelligent, personalized, interface (HIPI) integrating elements from smart textiles, sensors, semantic technologies, image processing, face and object recognition, machine learning, affective computing, and gamification.

The varied nature of experiences and needs of persons with deafblindness imply that such a system will need to be modular and reconfigurable, so that it can be adapted to different individuals' needs. SUITCEYES aims to provide a first step towards such a system, developing a suite of sensors and actuators that can be combined and configured to fit a variety of user needs and provide a basis for future research. The system's elements are shown in Figure 4.

Figure 4: Schematic overview of the system's components.

A range of potential feedback modalities will be explored for inclusion in the HIPI: vibration, pressure and temperature, as well as exploring different ways in which these can be combined or positioned to provide different signals.

Likewise, a variety of sensors will be explored to provide information about the environment: ultrasonic distance sensors to detect proximity of obstacles, a camera feed to allow recognition of objects or people, indoor positioning systems to help locate objects, or radio frequency identification to identify when given objects come near. A processing unit will be used to interpret sensor input against a knowledge base and determine appropriate feedback. Smart textiles will be used to accommodate sensors, feedback units and the processing unit on different parts of the body, either mounted on the textiles, or built into them, as appropriate.

3.1 Wearables and Smart Textiles

Wearables have become an important domain, embracing watches, smartphones and smart glasses [7]. Still, textiles are perhaps the ultimate class of wearables, playing a profound role in daily life of humans of whatever age, sex, health status, occupation, or activity level. Textiles are ever-present, offer high comfort, low weight and are very close to the human body.

Inherent properties of textiles – pliability, drapability and softness – make them tactual objects from the beginning. Textiles can become “smart” active haptic communication units by adding functionalities such as sensing [8], [9], monitoring [10], actuation [11], [12] (Figure 5). Especially textiles with the possibility to adapt to the environment are often called smart textiles [13]. As Profita et al. point out, “textile-based wearable computing systems have the ability to assist and augment the human sensory network by leveraging their close proximity with the skin to provide contextual information to a user” [14].

Figure 5: Smart Textile with conductive elements. [Photo from the Textile Showroom of University of Borås by Oliver Korn]

For users without disabilities, such smart garment interfaces can offer a sensory augmentation. However, for persons with impairments or disabilities, the benefits are substantial: smart textiles can partially replace the impaired senses. It is already possible to integrate a broad spectrum of mechanisms especially for haptic communication within common textile processing methods such as weaving, knitting, embroidery and sewing. Mechanisms include vibrotactile [15] and pressure [16] modes – all of these will be explored to extend the communication space of deafblind users in the SUITCEYES project.

3.2 Haptic Psychophysics

Important factors in the design of assistive wearables that should be taken into account are how well humans can discriminate and recognize different stimulation patterns. Moreover, stimulation should not be painful or irritating, the patterns should be relatively easy to learn, and they should not require too much attention. Although in recent years much research has been done (for example, on vibratory [17] or thermal [18] stimulation), design requirements for specific groups cannot simply be “looked up in a handbook”.

In the SUITCEYES project, psychophysical experiments will inform the designers about the requirements of persons with deafblindness. In systematic and extensive tests, users will be exposed to certain types of stimulation to investigate all kinds of relevant aspects of the stimulation, such as the intensity, the resolution, pattern identification, etc. At first, we will focus on dedicated laboratory set-ups, but at later stages, prototypes of garments will be tested.

The psychophysical techniques and the subsequent statistical analyses that will be employed in this project have already been described [19]. Depending on the types and number of prototypes, the most suitable method will be chosen. We foresee the following possibilities:

- **Discrimination:** The task is to decide which of a pair of stimuli has the higher intensity of the property of interest. By repeating this with varying intensity differences, the minimum noticeable difference can be determined for each property (Figure 6).
- **Magnitude estimation:** The task is to provide, on an arbitrary scale, a numerical estimate of the perceived intensity of the stimulation of interest. By testing a series of stimuli with different intensities, the relationship between physical and perceptual properties will be obtained.

Figure 6: Participant comparing two stimuli placed in a temperature-controlled box. [Image by Astrid Kappers]

As psychophysical experiments are very time-consuming, testing in earlier stages will be done with blindfolded sighted and hearing participants. Involving persons with deafblindness at this stage is not necessary as all humans have the same touch receptors. At more advanced stages, individuals with deafblindness will test the prototypes: their feedback and involvement in the development of the solution is central to our approach. Also, already in the early stage we will stay in close contact with the community of persons with deafblindness and take their ideas and preferences into account.

3.3 Haptic and Thermal Feedback

In human computer interaction (HCI), feedback is a key element. There is a huge community researching assistive technologies for persons with physical or cognitive impairments, for example in the context of SIGACCESS (ACM Special Interest Group on Accessible Computing) [20] and the related ASSETS conference. However, most research focuses on impairments of one major sense, whereas combined sensory impairments are rarely in focus – probably also because it is difficult to approach users with multiple impairments. Nevertheless, much research for users with visual or hearing impairments can be used or adapted for people with deafblindness.

Haptic feedback has received a significant amount of research, particularly in (but not limited to) the area of HCI. It comes in a variety of forms:

- **Force feedback** simulates contact by using actuators to apply forces in response to movement. For example, various degrees of mechanical impedance can be simulated by accelerator pedals becoming stiffer above a certain speed [21].
- **Vibrotactile feedback** uses vibration motors to provide feedback: its most familiar uses are “rumbles” in videogames or alerts on smartphones, but it can also be used in quite nuanced ways, such as the display of variable stiffness through different vibration intensities [22]. Such uses can well be adapted for communication purposes of deafblind persons.
- **Electrotactile displays** use an electric current to stimulate nerve endings in the fingers, thus recreating tactile sensations [23].

As navigation and the detection of obstacles are an evident form of assistance deafblind users require, there are already some applications using haptic feedback: the EyeCane [24] uses vibrotactile feedback to alert the user to nearby obstacles, the Haptic Taco [25] adjusts its shape to guide users towards a target.

Interestingly, when compared to haptic feedback, thermal feedback is a relatively new area of research in HCI. Early research starts in 2012 with “thermal icons” [26]. In the last years, especially the Glasgow Interactive Systems Group, namely Graham Wilson and Stephen Brewster, have advanced this area. A main focus is the strong connection of affect and thermal feedback: it has been connected to models of emotion [27] and there even are technical approaches to diversify the range of communication for thermal feedback by using an array of three thermal stimulators [28]. These emotional potentials in communication will feed very well in the areas gamification and “life enrichment” targeted in the SUITCEYES project.

3.4 Recognition of Objects and Persons

Providing users with vision and hearing impairments with artificial capabilities for real-time object detection and face recognition will significantly extend their perception of the environment: from the limited area reached by stretching their arms to a much larger area. Thus, the solution we are developing in SUITCEYES will augment their feeling of safety and security.

The current state of the art in face detection and recognition incorporates breakthroughs from deep neural networks [29], which gave rise to new facial point detection and recognition algorithms. In this context, deep architectures, such as deep convolutional network cascade [30] almost solved the face detection problem. Face recognition algorithms, like Deep Faces [31] and VGG-Face descriptor [32] deployed deep convolutional

architectures and achieved very high accuracy classification rates in unconstrained datasets.

On the other hand, state of the art techniques in object detection use deep convolutional neural networks to represent objects inside images. They train the parameters and weights of their models on large datasets and use a spatial window to localize object candidates inside the images. Processing intensive sliding window methods with part-based models have been replaced by selective search [33] and other sophisticated techniques that employ multi-scale bounding boxes instead of dense sampling. The current state of the art has turned its attention to developing faster, rather than more accurate techniques, while some more recent techniques such as YOLO [34] and SSD [35] achieve even lower computational cost, rendering them more than appropriate for embedded vision purposes – for example in a wearable.

SUITCEYES will extend the face detection and recognition state of the art by leveraging facial point detection and a combination of shallow features with a deep convolutional framework [36]. Regarding object recognition, similar hybrid representations will be deployed, combined with the selective scheme that YOLO uses, in order to design a low computational cost and accurate system, specifically tailored for embedded vision purposes [37].

From a technical perspective, video will be captured in HD resolution with a good frame-per-second capturing (4-8 FPS). For example, when using a mobile camera plugged onto a JetsonTX2, the frames will be stored on local memory. Facial and object detection algorithms will apply facial point detection and selective search algorithms within the captured frames, so that they can find the candidate bounding boxes that contain faces and objects in each video frame. A hybrid shallow-to-deep representation will be used to describe the appropriate features for recognizing familiar faces and objects inside the provided bounding boxes. These hybrid features will be classified based on pre-trained face and object databases.

3.5 Gamification and Social Interaction

As pointed out before, deafblindness is a severe condition. Especially persons who lost their hearing and seeing capabilities due to accidents or due to illness, typically experience these limitations as burdening and depressing. In our project we acknowledge this problem. However, we aim to move towards playful challenges, which extend the users' interests, add engagement and offer joyful experiences. The way towards this is the gamification of everyday situations and learning.

Gamification is the integration of video game elements into non-game services and applications, to improve the user experience, engagement and performance [38]. In areas like education [39] and health [40], gamified approaches are already quite popular and successful. They even have been incorporated in work environments [41], for example in production [42] and in the automotive domain [43]. However, like most games, gamification focuses on the visual and the auditory channel. For people with deafblindness, these methods are not feasible. Although there are already elements of vibration in gaming (e.g. rumble controllers), these elements just aim to enrich an existing experience. If a user experience is to be not just enriched but constituted by haptic or thermal feedback, gamification concepts need to be strongly adapted and partially re-invented.

Therefore, new designs and concepts with positive feedback loops are developed. The first step is to grasp the deafblind persons' concept of playfulness. What makes a person with deafblindness laugh, what is considered humorous?

This requires intensive involvement of the users, their families and the care providers. Their input is fed into an iterative agile development process. However, measuring the level of fun and enjoyment is difficult. The most common ways for evaluation are interviews and surveys. Since these methods can be problematic for some users in this target group, also methods from affective computing will be used. For instance, facial expression analysis can be used as means to directly assess the engagement of a user [44]. Another way to deduce positive effects of gamified scenarios are structured records of the families and educators of the users. These close persons often notice mood changes.

The most desirable result of the integration of gamification is to create a motivating flow state [45], an area where skill level and task affordance converge and a good performance is achieved seemingly easily. This enables users with deafblindness to increase their communicative space while enjoying themselves.

So a haptic intelligent, personalized, interface (HIPI) is integrated in a wearable, making it smart (section 3.1). However, how does this offer ways to gamify everyday experiences? An exemplary scenario is the "Easter Egg Hunt": the HIPI's haptic and thermal actuators guide a person with deafblindness towards a target object. Temperature changes of the thermal actuators and vibration of the haptic actuators indicate the proximity (section 3.3). The person with deafblindness is moving according to this feedback. This process may sound straightforward. However, not only does the system require the capability to navigate the user around obstacles (section 3.4), the user also has to "learn" to read and interpret the signals (section 3.2). Within a safe environment, the Easter Egg Hunt offers a way to make this learning process fun. If the users become more proficient, it can easily be extended to include social interaction, for example by playing "Hide and Seek": an everyday game for most children, which currently is utopia for users with deafblindness.

As described in the introduction, innovations in assistive technologies often remain unused and discarded. Enriching both the learning and the usage processes with gamification will increase the motivation to use the solution. Like with learning a language or a musical instrument, the first steps are the most painful ones. Only over time, and potentially only if it is fun to learn, the process of using the HIPI will get fast and proficient.

4 CONCLUSIONS AND FUTURE WORK

In this paper, we introduced the vision of a haptic intelligent, personalized, interface (HIPI) that integrates elements from smart textiles, sensors, semantic technologies, image processing, face and object recognition, machine learning, affective computing, and gamification. This solution is being designed in a user-centered and agile process for the community of deafblind persons. Their special situation has been described in section 2.

In section 3, we presented the five underlying concepts: Wearables and Smart Textiles (section 3.1), as the solution needs to be portable and close to the users. Haptic Psychophysics (section 3.2) to design the stimuli best-suited for communication, which typically will be Haptic and Thermal Feedback (section 3.3). We described how the textile can become smart – using a Recognition of Objects and Persons (section 3.4). Finally, we discuss how Gamification and Social Interaction (section 3.5) can make the difference in motivating users to learn and "play" with the HIPI. The vision is that users with deafblindness extend their abilities while enjoying themselves.

Although there is a large community of people with deafblindness in Europe and all over the world (section 2), the local

communities are often not well connected. Work on the needs of deafblind persons is just beginning. We hope that this vision paper is a first step, and that the SUITCEYES project as a whole will make a difference.

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