SMART ACCESSIBILITY 2016

The First International Conference on Universal Accessibility in the Internet of Things and Smart Environments

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Lukas Smirek, Stuttgart-Media University, Germany

Kristin Skeide Fuglerud, NR–Norsk Regnesentral, Norway

SMART ACCESSIBILITY 2016

Forward

The First International Conference on Universal Accessibility in the Internet of Things and Smart Environments (SMART ACCESSIBILITY 2016), held between July 24-28, 2016 in Nice, France, was an inaugural event covering topics related to universal accessibility, such as design for all, universal design, inclusive design, accessible design, and barrier free design.

We take here the opportunity to warmly thank all the members of the SMART ACCESSIBILITY 2016 technical program committee, as well as the reviewers. We also kindly thank all the authors that dedicated much of their time and effort to contribute to SMART ACCESSIBILITY 2016.

We also gratefully thank the members of the SMART ACCESSIBILITY 2016 organizing committee for their help in handling the logistics and for their work that made this professional meeting a success.

We hope SMART ACCESSIBILITY 2016 was a successful international forum for the exchange of ideas and results between academia and industry and to promote further progress in the area of universal accessibility. We also hope that Nice, France provided a pleasant environment during the conference and everyone saved some time enjoy the beautiful French Riviera.

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New Controlling Technique between Smart Devices Using Inaudible Frequency in Noise Environment

Myoungbeom Chung
Division of Computer Engineering
Sungkyul University
Anyang City, South Korea
e-mail: nzin@sungkyul.ac.kr

***Abstract*— Recently, existing technologies such as Wi-Fi socket communication, Bluetooth communication, Wi-Fi direct, etc., are used to control smart devices which are in close vicinity. However, those technologies have some problems. One problem is that the Wi-Fi socket communication cannot work when the socket server is not working. Another problem is that Bluetooth or Wi-Fi direct cannot work, if the Operating System (OS) of each smart device is different. Therefore, to address these problems, we propose a new control method for smart devices in close vicinity using high frequencies. High frequencies are mixed control signals, which are using 18 kHz ~ 22 kHz frequencies of audible range; most people cannot hear these high frequencies. Indeed, because the proposed method only uses the microphone and the speaker of smart device, there is no need for extra communication modules or communication server. In addition, it can be applied to most smart devices without reference to any OS. To evaluate the efficacy of the proposed method, we developed a music control application and a music player, to which we applied the proposed method. Then, we experimented with the developed applications at various distances and the control success rate was 97%. Moreover, when we use the high frequencies proposed method, the signal recognition rates of people close by was 5%. Therefore, the proposed method could be a useful method for control between smart devices in near.**

Keywords-Wireless communication; Signal processing; inaudible frequency; Controlling technique.

I. INTRODUCTION

The recent addition of modules to smart device has improved their performance and allowed users to perform activities such as playing games, listening to music, and watching movies. Individuals have begun to use more than a single smart device and to share data among smart devices. For example, an iPhone 5s user might also buy an iPad Air for its wide screen and fast data processing. The iPad Air user might also use a Galaxy S4 based on the Android OS. At first, socket communication involving Wi-Fi and servers was used to share data among smart devices [1][2]. Near communication methods using the Bluetooth module and Wi-Fi direct function have also been developed [3][5]. In addition, various communication methods use control technology between smart devices [6][10]. However, Wi-Fi-based socket communication technology requires a socket server, and if the socket server does not work, smart devices cannot share data or be controlled. Although Bluetooth technology does not need a server, pairing is needed to share data. In addition, Bluetooth technology has another weakness: It can be used only with devices with the same OS. Wi-Fi direct and Airdrop technology also have this weakness. Therefore, we need a new near control communication technology which enables sharing data between or controlling smart devices without pairing and regardless of OS.

Therefore, we propose a near control technology using high frequencies and the internal microphones and speakers of smart devices. High frequencies are sound signals which most people cannot hear and are between 18 kHz and 22 kHz of the audible frequency range (20 Hz–22 kHz). We use these high frequencies as control signals. Earlier research using high frequencies applied ultrasonic waves used by bats for measuring the distance to objects or finding obstacles, and most researchers studied tracing the position of people in indoor environments using high frequencies [11][12]. Bihler named high frequencies ultrasound waves and used them to trigger signals for data transmission to smart devices [13]. In this paper, we seek to improve the high frequencies of Bihler and to apply them as control signals between smart devices at a near distance. The high frequencies used by Bihler could introduce errors from sounds in the environment, so we protected against error generation by using two high frequencies: the first to send and the second to end it control signal. The first uses frequencies in the 18–22 kHz range, while the second uses only a fixed frequency.

To evaluate the performance of the proposed method, we developed a music remote control (control sender) and music player (control reception) applications to which we applied the proposed high-frequency method. We conducted a control experiment of the proposed high-frequency method using the two developed applications at various distances. The results showed a control accuracy of 97% within 5 m. When using the proposed high-frequency method, we tested how many people recognized the signal, resulting a recognition rate of less than 5%. Therefore, the proposed high-frequency method is useful in near wireless control between smart devices.

This paper is organized as follows. Section 2 explains the high frequencies used in the proposed method and the algorithm for the processing of the high frequencies in the smart device. In Section 3, we describe the music remote control and player applications. Finally, in Section 4, we discuss the results of the control experiment regarding the performance of the proposed method, and we present the conclusions.

II. INAUDIBLE FREQUENCIES FOR CONTROL AND CONTROL METHOD BETWEEN SMART DEVICES

This section explains the high frequencies used in the proposed control method between smart devices. The proposed high frequencies are between 18 kHz and 22 kHz. Two high frequencies are used in the proposed method. The first high frequency carries control information, so it uses one changeable frequency from 18 kHz to 22 kHz. The second high frequency sends only control end information, so it uses one fixed frequency. Thus, the proposed high frequencies consist of, first, a changeable high frequency and, second, a fixed high frequency as a control signal. The generating time of the first high frequency is m seconds and of the second high frequency n seconds. The reason for using two high frequencies in order is to prevent errors caused by unexpected noises in the environment. Fig. 1 presents an example of the proposed high frequencies. In Fig.1, the first high frequency uses 19 kHz and 20 kHz for the control signal, and the second high frequency 18 kHz.

As shown in Fig. 1, when the control device sends 19 kHz for the first high frequency over 0.2 s and 18 kHz as the second high frequency over 0.2 s, the smart device which receives the control signals completes analysis of the high frequencies at 0.5 s and executes a specific operation using the control signal (①). When the control signal sends 20 kHz over 0.2 s and 18 kHz over 0.2 s in order, the smart device completes analysis of the high frequencies at 1 s and executes another specific operation (②). In the example presented in Fig. 1, m and n seconds are both 0.2 s. We can see that, although noise occurs from 0.4 s to 0.5 s of the ① control signal and another noise occurs from 0.8 s to 0.9 s of the ② control signal, the proposed high frequencies work well. Figure 2 shows the work flow of the control method between smart devices using the proposed high frequencies.

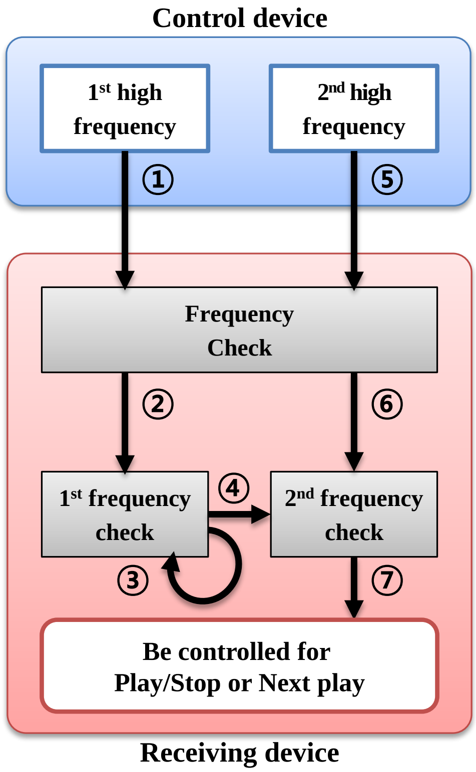


Figure 2. Work flow of proposed method using high frequencies

As shown in Fig. 2, when the control device sends the first high frequency (①), the receiving device uses a fast Fourier transform (FFT) algorithm to decide whether high frequencies are from the surrounding environment (②). If a high frequency is detected, the receiving device repeatedly checks if that same high frequency is sent consistently. If the high frequency continues for m seconds (③), the receiving device stops checking the first high frequency and waits for the second high frequency as the control end signal (④).

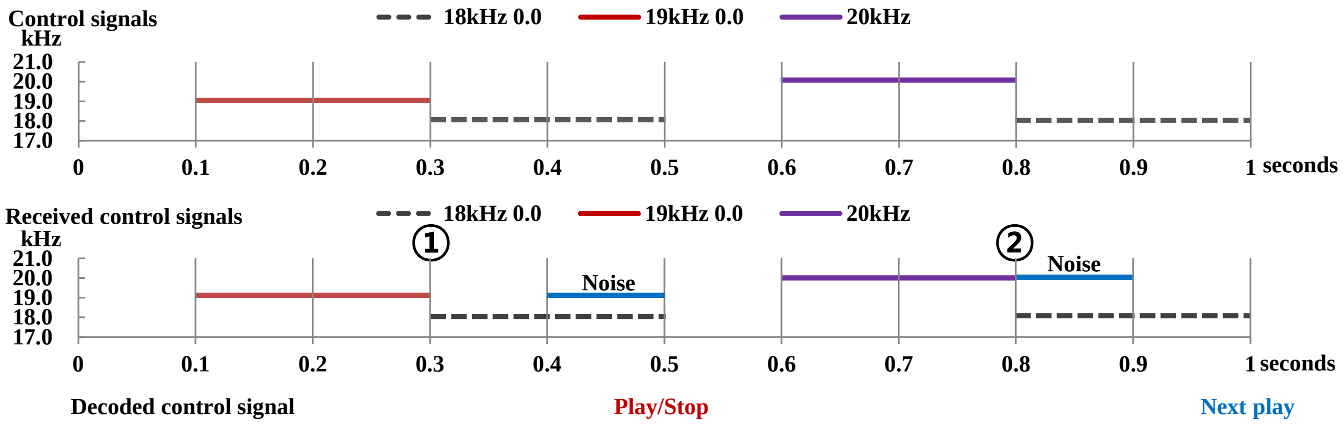


Figure 1. The example of proposed high frequencies for control between smart devices

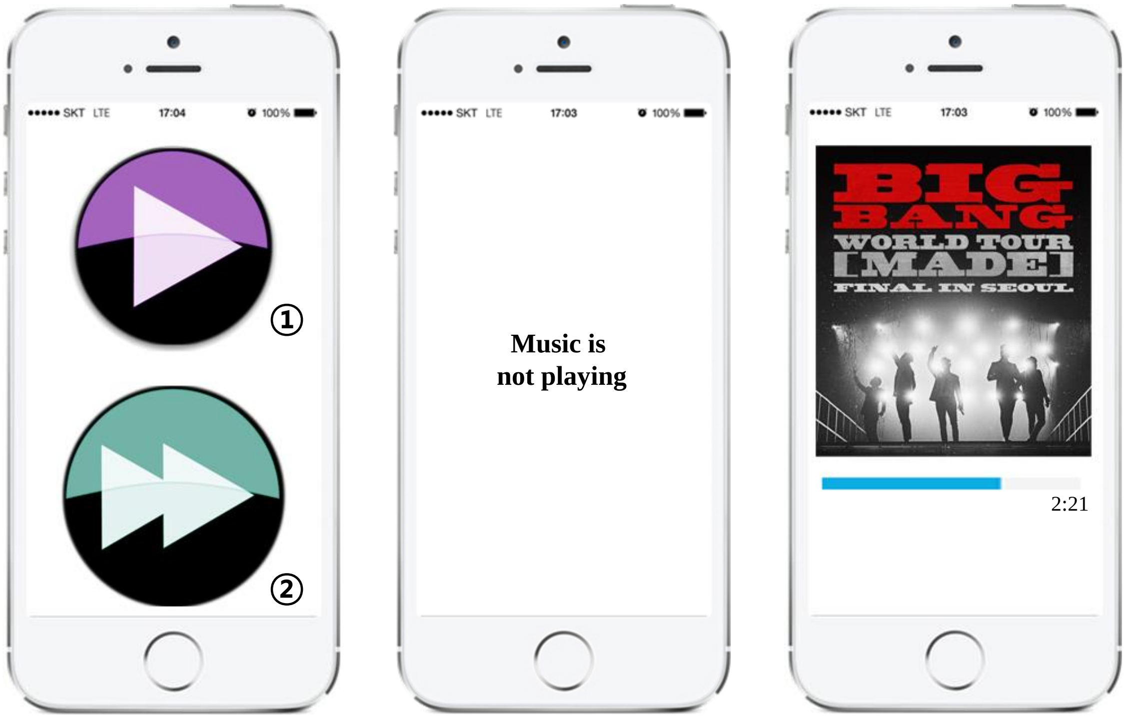
Then, if the control device sends the second high frequency (⑤), the receiving device recognizes the second high frequency over n seconds (⑥) and executes a specific operation (⑦).

III. EXPERIMENT WITH AND ANALYSIS OF THE PROPOSED CONTROL METHOD USING HIGH FREQUENCIES

This section describes the music remote control and player applications developed and the results for the performance of the proposed method's performance in the control experiment. The music remote control application sends the control signal from the control device, as described in Section 3, and has a toggle button, which can play and stop songs on the receiving device, and a next button, which enables moving to the next song (see Fig. 3(a)). The toggle button (①), which starts and stops songs (Fig. 3(a)), uses 19 kHz as the first high frequency and 18 kHz as the second high frequency. The next button (②) (Fig. 3(a)) uses 20 kHz as the first high frequency and 18 kHz as the second high frequency. We use 0.2 s as m seconds of the first high frequency and 0.2 s as n seconds of second high frequency. The music player application receives the proposed high frequencies and plays a song (Fig. 4(b) and (c)). The music player application starts with the "Music Stop" screen (Fig. 4(b)). When it receives the high frequencies for playing songs from the music remote control, the music player application displays song information and plays the song (Fig. 4(c)). The image (①) in Fig. 4(c) shows information about the song being played and a progress bar (②), indicating the duration of the song.

We tested the accuracy of the proposed high-frequency method when varying the distance between the music remote control and player applications. The tested distance between the smart devices was 1 m and 5 m, with 100 tests performed at each distance using the play, stop, and next buttons. The test environment was a laboratory with a quiet indoor environment with a noise level of approximately 40 dB, the average noise level in homes. Figure 5 shows the results for distance from the control experiment. The accuracy of all control operations within 3 m was more than 95% and within 5m, more than 95%. While the music player application was playing, the accuracy of the stop and next control operations was 96.8% within 5 m. Thus, the proposed high frequencies are robust amidst interference from other unexpected sound signals.

Next, we tested the recognition rates among surrounding people when using the proposed high frequencies. The experiment environment was the same as in the previous experiment, and the distance between smart devices was 3 m. Each control operation was performed 10 times, and the 10 participants were students in their 20s who were in the same place for each operation. The signal recognition experiment noted the number of count cognitions among participants when using high frequencies, Table 1 shows the results for signal recognition using the proposed high frequencies.



(a) (b) (c)

Figure 3. The music remote and music player applications applied the proposed method: (a) The main screen of the music control remote application, (b) The screen of music player application when song stops, (c) The screen of music player application when song is playing

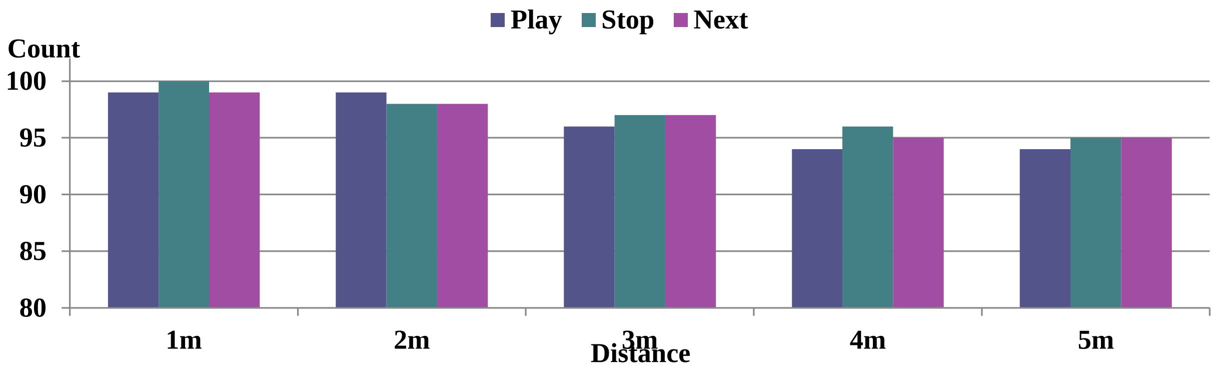


Figure 4. The result of control operation using high frequencies according to distance between smart devices

TABLE I. THE RECOGNITION RESULT OF PARTICIPANT ABOUT HIGH FREQUENCIES FOR CONTROL

Control	Play	Stop	Next
P1	0	0	0
P2	0	0	0
P3	0	0	0
P4	6	2	1
P5	0	0	0
P6	0	0	0
P7	0	0	0
P8	0	0	0
P9	2	1	2
P10	0	0	0

As shown in Table 1, participants' average recognition value was less than 5%. When it was silent, 1 of the 10 participants recognized the high frequencies 6 times, while another recognized the high frequencies twice. Eight participants did not recognize the proposed high frequencies. When a song was playing, 2 participants recognized the control signal. One participant recognized twice and another once. Participants recognized high frequencies in the stop operation less frequently than in the play operation, even though the 2 control signals used the same high frequency. This difference likely is explained by the playing music which covered the sound of the high frequencies. Two participants recognized the high frequencies for the next operation, which were different than the play and stop operation frequencies. The next high frequencies were generated while a song was playing; 1 participant recognized the signals once and 1 participant twice. After the experiment, we conducted a hearing test for the 2 participants who recognized the proposed high frequencies and found that they could hear the 18 kHz high frequency. However, the average recognition value of the 3 operations using proposed method was less than 5%, so we confirmed that the proposed high frequencies did not affect people in the area of the smart device.

IV. CONCLUSION AND FUTURE WORK

In this paper, we have shown that the proposed method using high frequencies can effectively control smart devices at a close range without a socket server or pairing. This method can easily use any OS on smart devices, even if the smart devices have different OS. Therefore, the proposed high-frequency method can be a useful technology in networking fields, such as near wireless communications and near control between smart devices.

In future research, we will study the effectiveness of advertisement technology in smart televisions using the proposed high frequencies with smart devices. Additionally, we will research new signal processing technology for data and information transmission using only high frequencies.

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A Review of Universal Design in Ambient Intelligence Environments

Aleksander Bai, Heidi Camilla Mork, Till Halbach,
Kristin S. Fuglerud, Wolfgang Leister, Trenton Schulz
Norwegian Computing Center, Oslo, Norway
Email: {`aleksander.bai, heidi.mork, kristin.skeide.fuglerud`
`till.halbach, wolfgang.leister, trenton.schulz`}`@nr.no`

***Abstract*—This work summarizes the state of research in universal design in ambient intelligence environments. We provide a detailed background, specify relevant research areas, and review research in these areas. We discuss the findings and put them into perspective with regard to universal design and accessibility in smart environments, and point out research shortcomings concerning ambient intelligence and hybrid interactions. Our findings show that the majority of related work needs stronger emphasis on aspects related to universal design in general; universal design in ambient intelligence; universal design in multimodal interactions; and universal design in security, privacy, and other ethical aspects of smart environments.**

***Keywords*—Universal design; ambient intelligence; multimodal interaction**

I. INTRODUCTION

The United Nations Convention on the Rights of Persons with Disabilities (CRPD) [1] aims to ensure that people with disabilities can enjoy the full range of human rights: civil, political, economic, social, and cultural. Besides the requirements for accessible ICT (Article 2), the Convention refers to universal design (UD) as a means to achieve this goal (Article 4). UD is the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design [2].

Universally designed smart environments have the potential to improve the mental and social well-being of individuals as well as their economy. People with disabilities will have increased independence with a reduced need for aid, other support services, and personal assistants. Smart environments in the workplace mean that a person with disabilities can get work experience early on. This has a direct positive effect for the person and increases the probability of being in the workforce and contributing to society in the future [3].

Stevenson and McQuivey [4] find that 57% of working-age people with mild to severe difficulties or impairments are likely or very likely to benefit from accessible technologies when they use computers. The increased social, cultural, and economic participation of this group is likely to improve their health, which in turn influences their human and economic development positively [5]. Looking at the economic side, the participation of a larger part of the population in the workforce – including people with disabilities – is the key to fostering economic growth: a larger workforce should lead to increased tax incomes and reduced welfare and health expenses. Creating structures and systems to accommodate people with disabilities facilitates the retention and return to work of other workers as well [5].

Yet the focus for smart environments or ambient intelligence (AmI) has mainly been on technology and its capabilities. User-centric design and accessibility are often neither part of the design nor the evaluation process [6]. A vital part of AmI environments implements interactions between users and the environment. To make these interactions accessible and usable for *diverse people* (all people, including people with different types of disabilities) the interfaces must be flexible and offer interaction through different types of modalities [7].

Although multimodal interactions constitute an important concept in universally designed AmI, many AmI solutions lack the aspect of multimodality. It seems we are long way from the *disappearing computer* scenario proposed by Weiser [8]. In this scenario, devices are concealed into everyday objects and everyday interaction modalities, and people spontaneously interact with digital objects as they do with physical ones.

We refer to a combined physical and digital environment as a *hybrid environment*. A universally designed hybrid environment enhances the surroundings with ambient intelligence and digital interfaces so humans can interact according to their abilities and preferences. In this context, a *hybrid interaction* may comprise of both input and output in various modalities and interaction types.

The remainder of the paper is organized as follows: After a summary of the current knowledge state within ambient intelligence and multimodal interactions (Sections II and III) we discuss the challenges of universal design in ambient intelligence and multimodal interactions (Section IV). Finally, we highlight research directions (Section V).

II. AMBIENT INTELLIGENCE

Ducatel et al. [9] define *Ambient Intelligence* (AmI) as a smart environment that supports its inhabitants. The vision for AmI is an environment that is unobtrusive, interconnected, adaptive, dynamic, embedded, and intelligent. Instead of communicating through a keyboard, mouse, and screen, people use implicit interaction with the objects in the environment [10], such as light sources, furniture, or household devices. The devices themselves can communicate with each other through the Internet of Things (IoT) to facilitate collaborative assistance of the environment. Other visions for AmI include that AmI environments can anticipate and predict the people's needs and behavior and provide services or interactions in people's preferred way [11].

AmI has become a complex, multidisciplinary research field and consists of several domains. There are multiple definitions of how AmI can support its inhabitants, but intelligent reasoning, multimodal interfaces, sensors and ubiquitous computing are elements that are usually required for an AmI. The development of AmI's requires specialists from fields like information and communication technology (ICT), psychology, social sciences, engineering, design, security, privacy, and humanities.

Kodratoff and Michalski [12] presents intelligent reasoning as a broad field built on well established theories and methods with machine learning at its core. Mikolov et al. [13] point out that building an intelligent reasoning system must incorporate many parts like models of human behavior, predictions about human actions, user preferences, large amounts of sensor data, and machine learning.

To personalize the environment for a specific person or group of people, a profile is usually built, based on the person's abilities and needs, preferences, context, and history. Large variations in what to store in a profile and how to apply the profile in a given context have been shown by van Otterlo [14]. Koller and Friedman [15] suggest using probabilistic models like Bayesian or Markov networks. These models can predict how likely someone wants to turn on the light, or how likely someone wants to use voice modality instead of textual modality.

Instead of modelling the probabilistic distribution of the data, a common approach is to look at the similarities between the examples using *kernel methods*. Bishop [16] defines a kernel as a collections of algorithms that look at the differences (more formally: distances) between examples in complex data structures. Possible methods suggested by Bishop include support vector machine (SVM) and principal components analysis (PCA).

In the field of human behavior and prediction, much work has been done on modelling human behavior with statistical models within machine learning algorithms [17]. However, due to the *curse of dimensionality* [18] that occurs when analysing high-dimensional spaces, the statistical models of people and their behavior are often too simplistic. Instead of only using statistical models, studies by Rosenfeld et al. [19] and An [20] have combined psychological models with machine learning and achieved good results in more complex domains. Another method used by Panagiotou et al. [21] is to apply machine learning algorithms to sensory data in combination with personal data. A more recent approach for personalization is to build a model for each user from a large dataset. Ghahramani [22] call this the *personalization of models*. Suitable methods for solving these problems include hierarchical Dirichlet processes [23] and Bayesian multitask learning [24].

For an intelligent system to learn and adjust to users, it needs information from sensors, actuators, and monitoring tools. Liu et al. [25] have connected sensor output to high-level intelligence, and Sun et al. [26] have worked on predicting human routines from sensor data. Deep learning and convolutional recurrent neural networks have lately gained much attention in voice and image recognition, but have also given results in activity recognition as shown by Ordóñez and Roggen [27]. Wiering and van Otterlo [28] have used reinforcement learning and feedback loops in a learning system. A vital part of reinforcement learning is the reward function that motivates model adjustment. Barto [29] has incorporated human motivation into these models.

There are several AmI frameworks. Karakostas et al. [30] created a sensor-based framework for supporting clinicians in dementia assessment with several wearable sensors used on the patients. Blackman et al. [31] identified 59 technologies that have been developed for ambient assisted living for the elderly. They also indicate that more research should be done on middleware and integration.

Home environment is probably the most dominant area of application for AmI. Often described as smart or intelligent homes, the integration and utilization of multiple sensors are the center of attention. The goal is to improve quality of life by performing everyday tasks automatically and improve safety by preventing and detecting accidents. For instance, an oven can be equipped with a database of recipes with oven temperature, timing, and method of heating, as demonstrated in the GENIO Project [32].

Ambient assisted living for elderly is another application area in AmI. The goal is to increase the quality of life by providing health care in domestic homes. Kientz et al. [33] show how AmI can monitoring medication use and alert caretakers in case of a person's fall. Other AmI application areas include shops, museums and driving [11]. Lately, also the working environment has seen some progress, with the goal to get more people back to work and to accommodate people at work. The SMARTDISABLE Project aims at including people with disabilities in the workplace by means of ICT equipment with voice control [34]. Another example is a fatigue-sensitive chair aimed at workplaces to alert the user to rest or take a break [35].

Despite many promising applications, only a few evaluations show how AmI solutions works in practice. Gövercin et al. [36] conducted a study with 35 households as part of the SmartSenior@home project, but there are few other evaluations at this scale. There are also few studies that involve real users in the evaluation phase. Often, as shown by Wilson et al. [37], the results show a mismatch between expectations from the users and the developers and designers.

III. MULTIMODAL INTERACTIONS

Humans interact with the world in a multimodal way by using multiple perceptual modalities, both in parallel and sequentially. Turk [38] introduces the concept of *multimodal human-computer interaction* (HCI) as the attempt to provide similar capabilities to computers, and multimodal interfaces are intended to deliver more natural and efficient interaction.

Jaimes and Sebe [39] define a multimodal HCI system as one that responds to input in more than one modality, where modality is understood as communication according to human senses. We would extend the definition of *multimodal interfaces* to include input and output in more than one modality.

There is extensive research on interactions with modalities like visual, auditory, cognitive, touch, gesture, reach, and tactile. Covering all of them is beyond the scope of this paper, but some concepts that have shown good results across different modalities are mentioned here: Ullmer and Ishii [40] define a *tangible user interface* as an interface that couples physical representations with digital representations in a way that leads to interactive systems mediated by computers, and not identifiable as computers. The various meanings of tangible interactions in different science fields are summarized by Hornecker and Buur [41], and common characteristics are tangibility and materiality, physical embodiment of data, embodied interaction, and integration in real space. Recent research on tangible user interfaces includes work on haptics to improve the use of touch screens by Zimmermann et al. [42], and work by Bianchi and Oakley [43] on the use of *magnetic appcessories*, i.e., robust physical interfaces with magnets in interaction with a mobile phone and its built-in magnetometer.

Ferati et al. [44] studied the design of *audemes* (short non-speech sound symbols composed of music and sound-effects) with the goal of highest possible meaning recognition. Audemes can be used as a complement to visual output and to leverage more of the auditory capacities of people with vision impairments. The use of auditory modalities is useful in many case, for instance in eyes-free activities like driving or running. Rohani Ghahari et al. [45] study how one can browse the web on mobile devices with aural flows.

Takeuchi [46] has done work on digitizing architectural spaces, but there are no studies that try to bring the different architectural concepts together to facilitate multimodal interactions. In addition, Takeuchi [46] has proposed habitable user interfaces (HUIs) intended to fulfill the disappearing computer vision by digitalizing the environment. Here, the environment can be as easily transformed as changing the desktop wallpaper background on a modern computer. However, more studies that try to integrate all the different concepts into a complete environment are needed.

In a universally designed AmI environment, multimodal interactions are critical for adaptation purposes. Oviatt [47] and Obrenovic et al. [48] found that interfaces must handle multimodal input and output depending on a person's personal abilities, preferences, and the environmental conditions. The use of multimodal interfaces is one step towards universally designed interaction, but the interaction still must be usable and accessible. For example, a person must understand that a modality (e.g., auditory interaction) is available and know how to use it; the availability of a modality is not enough.

Fuglerud [7] found that introducing several modalities into an interface may make it more complex and, thus, less usable. Much work has been done on multimodal interaction and human-computer interaction, but Turk [38] found that only a minority of these studies focus on UD. Moustakas et al. [49] found that the translation from one modality to the other, an essential part of universally designed multimodal interfaces, is often limited to vision and voice modalities. Alce et al. [50] noted that more studies including diverse people and a larger number of participants is needed.

Homola et al. [51] found that when several humans are in one AmI environment, several types of conflicts can occur, from modality conflicts to goal and action conflicts. Resendes et al. [52] list the extensive research on resolving such conflicts, but Carreira et al. [53] point out that little work has been done with multimodal output conflicts. Also, usability and UD have not been focused on. For effectively working AmI environments, these challenges need to be solved.

IV. DISCUSSION

The idea of UD in AmI is to increase the degree of inclusion and life quality for users. As illustrated in Figure 1, the core entities are *diverse people & UD* (in the middle), *hybrid interactions*, *ambient intelligence*, and *things & environment*. These entities interact with each other, and UD is the key component that is infused in all the components.

Hybrid interactions, i.e., interactions between a user and digital and physical things in the environment must be adjusted for each user, based on preferences and abilities (profiles). The AmI will try to predict the best combination of interaction types and modalities for a given user or group of users. For instance, an older person with impaired hearing might prefer to speak actions out loud, but receive information visually in large type. This combination of interactions, however, might not be suitable for someone with vision impairment who may prefer to receive information as audio or tactile feedback depending on the context.

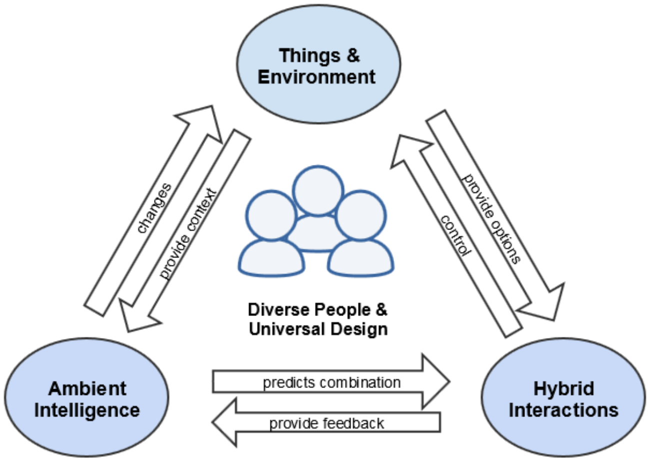

Figure 1. The core elements of universal design in ambient intelligence, and how they are interconnected.

The AmI must learn from previous interactions and associated contexts to improve and validate further predictions. Some things, like a smart rug, might not be able to use audio for interaction, while a talking door could support both visual and auditory interaction, but may not support tactile interaction. To our knowledge, research in AmI has not yet considered UD combined with human behavior and interaction prediction.

As illustrated in Figure 1, UD must be included in all parts of an AmI environment if the vision of AmI is to be fulfilled. As Wilson et al. [37] points out, most of the current AmI research does not have a clear understanding of who the users are and what their needs are, and this must get a stronger focus in the research fulfill the AmI vision.

O Shea et al. [54] note that the common approach for measuring UD is the use of checklists and expert evaluations as well as lab experiments, which are less feasible for practitioners. There are significant challenges in studying the impact of UD in the field, e.g., in buildings. Some of the difficulties include controlling for factors that may introduce confounding influences, e.g., the age of a building, occupancy type, activities occurring in the building, and its size. Sometimes, these issues have been resolved by conducting controlled experiments, or by comparing specific features in buildings, rather than evaluating the overall effect in the building.

The *participants activity index* documented by Danford et al. [55] is an example of a quantitative evaluation method. By means of crowdsourcing, Holone [56] found that users can play a central role in providing the accessibility information by using mobile apps. Moreover, Varela et al. [57] are considering autonomous evaluation, but current research appears to prefer conventional user interfaces rather than interactions. There is a need for research on methods and effective data gathering techniques for evaluating UD in AmI.

A. UD in ambient intelligence

Concerning the design of smart environments, Queirós et al. [6] posits that the limits of technology have been studied rather than the actual people's needs. Tavares et al. [58] is working on ontologies for accessibility, and Catenazzi et al. [59] proposed guidelines for inclusive intelligent environments. More studies that focus on human-centered design and on meeting user needs are called for in the AmI literature [37], [6], [60]. There is also a lack of evaluations including people with disabilities and evaluations in real-life environments.

Corno et al. [61] has proposed a set of design guidelines for user confidence in AmI environments. But there is little work on the cognitive and social aspects in the design of AmI environments nor how cognitive and social aspects can be combined with technology requirements.

Olaru et al. [62] list many AmI system architectures, but not many consider accessibility or UD as part of the system architecture. One platform that has a large community is the Global Public Inclusive Infrastructure (GPII) for making digital technologies more accessible by providing adaptive user interfaces in a cloud based infrastructure [63]. Other frameworks involving UD in AmI environments should be proposed and evaluated.

Currently, there is a lack of research regarding multiple cultures. Kaiying et al. [64] notes that most studies have been conducted in Western countries with a differing view on AmI as compared to non-Western countries. Hence, all cultures should be represented throughout the design, development, and evaluation phase of universally designed solutions.

B. UD in multimodal interactions

The UD aspect of multimodal interactions is deficient in the research, and Turunen et al. [60] requests studies that are more human oriented. This includes finding the best combination of multimodal interaction types and modalities for universally designed AmI environments [65]. Both the accessibility and the feasibility of possible interactions must be evaluated with broadly diversified users and cultures to evaluate what works best in practice.

While there are studies for multimodal output conflict resolution, the focus has not been on usability or UD [53]. If multiple interactions in different modalities are to be realized in an AmI environment, then more user studies must be done to evaluate conflict resolutions.

C. UD in security, privacy, and ethical aspects of AmI

Venkatesh et al. [66] details security-related work in AmI environments, and He and Zeadally [67] document how to provide secure system authentication. To preserve privacy within AmI, Gope and Hwang [68] propose architectures for ensuring that sensory output is untraceable. Sicari et al. [69] list projects that address general privacy and security aspects in the IoT.

Even though Nurse et al. [70] stress that usability is important for security, Realpe et al. [71] point out that UD has not been a focus area. Fritsch et al. [72] show that UD introduces additional challenges in relation to personalization, privacy, and the design of the security mechanisms themselves. Privacy is paramount when users interact with ambient environments. There is a need for anonymity and pseudo-anonymity, exemplified by systems which give people the choice to opt-in for the disclosure of their profile and data to the services. We did not find research that considers universally designed security and privacy solutions in the context of AmI and interactions.

Further, a review by Novitzky et al. [73] finds that ethical questions have not been a research focus of AmI and ambient assisted living; more research is clearly needed. Bibri [74] has suggested to implement safeguards for protecting privacy, but there is a lack of research not on how to incorporate ethical concerns during the development process in general and on ethics in combination with AmI and hybrid interactions. There is a need for research on how AmI solutions may affect autonomy, integrity, dignity, human contact, and human relations.

V. CONCLUSION AND FUTURE WORK

We have given an overview and highlighted some important issues and new areas for research in the field of universal design in AmI environments. Clearly, much research work remains. This view is also supported by several studies that point out the failure of meeting user needs. Even though there are guidelines for designing inclusive AmI solutions, there are very few user studies of AmI in general. There are even fewer studies that evaluate the AmI solutions for users with disabilities. Therefore, future work should develop AmI solutions that consider the full spectrum of user abilities and involves a number of diverse user groups throughout the entire development process, including users from different cultures.

It would be interesting to see more automated evaluation methods for measuring the effect of UD and usability in AmI environments. Methods like crowdsourcing and autonomous data gathering are possible ways to measure UD, and we believe that a higher degree of automation could in turn stimulate more user studies.

From our literature search, no AmI research has considered UD combined with human behavior and interaction prediction. Further, there seems to be a need for research on ethical and social aspects of AmI solutions.

Finally, security and privacy issues abound in AmI environments. Particularly, security and privacy mechanisms must be reliable and usable for diverse people. Future research should contribute to the development of novel, universally designed security mechanisms that offer comparable protection for all users as current regular systems.

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Accessible Control of Distributed Devices

Supporting Persons with disabilities by Providing Adaptive Interaction

Lukas Smirek, Gottfried Zimmermann
Stuttgart Media University
Stuttgart, Germany
email: smirek@hdm-stuttgart.de
email: gzimmermann@acm.org

Christos Mettouris, Marios Komodromos, Achilleas Achilleos, George A. Papadopoulos
Department of Computer Science, University of Cyprus
Nicosia Cyprus
email: {mettour, mkomod, achilleas, george}@cs.ucy.ac.cy

Daniel Ziegler
Fraunhofer-Institute for Industrial Engineering IAO
Stuttgart, Germany
email: daniel.ziegler@iao.fraunhofer.de

Michael Beigl
Karlsruhe Institute of Technology
Karlsruhe, Germany
email: michael.beigl@kit.edu

Abstract **– It is nowadays common that the growing number of electronic devices and services used in all kinds of environments is coming along with a significant increase in the complexity of offered functionalities, as well as higher dependencies between devices and services. In this context, two big challenges can be identified: firstly, how to offer appropriate interactions to heterogeneous groups of users, and secondly, how to overcome interoperability problems of heterogeneous devices and services. In this paper, we present a prototype that attempts to address the above mentioned challenges by enabling the integration of Adaptive User Interfaces and Middlewares aiming to support real life Assistive Technologies and Internet of Things scenarios. When developing this prototype, a key requirement was to address adaptivity, not only at the graphical level, but rather from a generic interaction perspective in order to also support persons with motor impairments in Assistive Technologies scenarios. Therefore, four technologies/frameworks were integrated: Global Public Inclusive Infrastructure, MyUI, Assistive Technology Rapid Integration & Construction Set, as well as Universal Remote Console.**

Keywords-Adaptive User Interfaces; Assistive Technologies; Platforms Integration; Smart Environments; AsTeRICS; MyUI; URC; GPII.

I. INTRODUCTION

In today's world, we are facing a growing number of electronic devices and services both in public and private places. Thereby, not only the amount of devices is continuously increasing, but also their functionality and their interdependencies are becoming more complex and demanding. These developments can be seen as the precursor of a future Internet of Things (IOT) and the related domains of smart environments and smart homes.

From a user perspective, it has to be taken into account that the increasing complexity coming along with these developments must still be manageable for the end user. As mentioned in [1], providing only more functionality is by far not enough to increase user satisfaction. Even worse, it can lead to frustration. Hence, approaches like user centred design and appropriate user interfaces are of great importance.

This is even more emphasized when we consider that, as the amount of electronic devices and services is increasing both in private and in public places, more and more situations in our daily lives are being affected. Hence, not only skilled computer users will face these devices, but also almost everybody independent from age, computer skill level, social background or disability.

Summing up, in an IOT environment we see a heterogeneous user group facing a tremendous amount of heterogeneous devices and services. This raises new challenges for an appropriate design of user interfaces to interact in such an environment.

The first challenge - appropriate user interfaces for a heterogeneous user group – can be addressed by the well-known approach of adaptive user interfaces [2]. Furthermore, middleware architectures are a well-established approach to overcome the second challenge - interoperability problems of heterogeneous devices and services. However, most systems address only one of these challenges.

In this contribution, we present a prototype developed during the Prosperity4all project [3] that incorporates adaptive user interfaces and middlewares for device overarching use cases. A further development goal was to not restrict adaptivity only to a graphical user interface but also to enable adaptive support for persons with motor impairments in Assistive Technologies (AT) scenarios.

With this goal in mind, the following four technologies/frameworks were combined in order to provide a system for adaptive user interfaces in distributed environments: (I), the Global Public Inclusive Infrastructure (GPII) [4] is used as a means to transfer platform independent user preferences from one application to another and to infer appropriate settings to adapt the target system's user interface according to the user's needs. The adaptive user interface layer is formed by a cooperation of the (II), MyUI framework [5] and (III), Assistive Technology Rapid Integration & Construction Set (AsTeRICS) [6]. MyUI is used to provide an adaptive graphical user interface and to enable device overarching user interfaces, while AsTeRICS is used to accommodate persons with motor impairments in AT applications. Finally, (IV), the Universal Remote Console (URC) runtime [7] is used to mediate between the user interface layer and the devices and services that shall be controlled. It is also used to give third parties, e.g., assistive technology experts, the possibility to make their own contributions.

The remainder of the paper is structured as follows: In section (II), an overview about related work is provided. In section (III), a theoretical model on how to support a heterogeneous user group in an environment with heterogeneous devices is developed. In section (IV), the for technologies that were used to build the prototype are described in more detail. Their integration and their interdependencies are than described in section (V). Section (VI) concludes the paper with a discussion about the developed prototype and possible test cases, as well as open research questions.

II. RELATED WORK

The potential of adaptive user interfaces to support persons with disabilities, as well as the requirements for their market adaptation are identified in [2]. Also, authors like Kleinberger et al. [8] and Abascal et al. [9] point to the potential of natural and adaptive interfaces in the field of Ambient Assisted Living (AAL).

In another dimension, a number of assistive technology systems have been developed, mainly in European Projects. The TOBI project [10] focuses on the design of non-invasive Brain/Neural Computer Interaction prototypes that combine existing Assistive Technologies and rehabilitation protocols. The aim is to improve people's communication by supporting access to devices such as virtual keyboards, internet, email, telephony, fax, SMS and environmental control. The BRAIN [11] project enhances intercommunication and interaction skills of disabled people via the development and integration of Brain-Computer Interfaces into practical assistive tools. The aim of the BRAIN system is to improve interaction of the user with people, home appliances, assistive devices, personal computers, internet technologies, and more. BrainAble’s [12] main objective is to assist people with disabilities in overcoming exclusion from home and social activities by providing an ICT-based Human Computer Interface, as well as producing a set of technologies suitable for assisting people with physical disabilities regardless of cause.

OpenHAB [13] provides a scalable and modular architecture that integrates components and technologies in a single solution. OpenHAB is mainly concerned with the integration of devices from the Smart Home domain. The project is open-source with an active community, which enables new features and functionalities to be added, as with AsTeRICS [6]. The restriction of OpenHAB, in comparison to the AsTeRICS framework, is that an expert developer is needed to define in the form of text-based scripts the interactions among the components even for a simple assistive technology scenario. In contrast, the AsTeRICS system enables a non-expert AT designer to use a simple modelling interface to easily model or re-use existing models to provide the necessary assistive technology functionality to the user.

An adaptive Ambient Assisted Living system developed for elderly people is the PIAPNE Environment [9]. It is based on three models: A user model (capabilities, permissions), a task model (user activity) and a context (environment) model. The system has several layers. The middleware layer bridges different network technologies and the intelligent service layer can be used to connect intelligent applications interfaces (only software).

The DomoEsi Project [14] is carried out at the Escuela Superior de Ingenieros de Sevilla and focuses on interoperability problems but uses also some simple, adjustable hardware controller devices. Universal Plug and Play (UPnP) serves as common interface from which software bridges to other Smart Home technologies can be built. The system can be accessed via web browser, a Nintendo Wiimote controller or a voice interface. The different input modalities of the Wii controller (infrared camera, buttons, accelerometers) can be used to provide a simple adaptable interface for people with disabilities and with other, special needs.

III. THEORETICAL BACKGROUND

In order to provide adaptive and device overarching user interfaces, two major layers of control are required: one being responsible for controlling the devices by the user and a second one for conducting the adaptation of the user interface. Furthermore, to make user preferences globally accessible, an internet based exchange mechanism must be available. Along with that, there must be an external repository for user interface components.

A. Device Control

As also described in [15] three layers of abstraction are required in order to control several devices by any adaptive user interface to integrate different devices and services. First of all, there must be a description available to give an abstract view on the devices’ and services’ internal states and functionalities *(da)*. Such descriptions can be seen as a kind of contract provided by the device and giving everyone the chance to access and operate it via its API. This is the lowest level of abstraction.

Next, there must be an abstraction from tasks. On this level the execution of functions on different devices and services is coordinated *(ta)*. Finally, a last layer is needed that abstracts from specific modalities and interaction between users and such a system *(ia)*.

B. Adaptive user interface Control

In order to control an adaptive user interface, three components can be usually distinguished. Here, we refer to the terminology of an afferent, an inferent and an efferent component as it is also used in [16]. The afferent component is responsible for collecting available and observable data about the context of use. The context of use comprises data about the user, the environment and the target platform. The data collected by the afferent component serve as input for the inferent component, in order to deduce relevant properties of the user interface that are needed to satisfy the users' needs in the current context. Finally, the efferent component is responsible for the generation of an appropriate user interface based on the conclusions made by the inferent component.

C. *Globally available user preferences and user interface components*

One characteristic of IOT environments is that the devices participating in an interaction situation, as well as the place where users would like to interact, can vary. Consequently, the part of the context of use that is related to the user must be globally available via the internet *(gu)*.

Moreover, users do not always know in advance under which kind of circumstances and with what kind of devices they will interact. Hence, a globally available repository for user interface components and user interfaces is needed that can be used for rendition *(gr)*. A further advantage of such a repository is that user interface experts and assistive technology experts can contribute alternative user interface fragments, even though the related device is already launched.

IV. TECHNOLOGY OVERVIEW

This section gives an overview of the technologies/frameworks used for this work.

A. *Global Public Inclusive Infrastructure (GPII)*

The broader vision of the GPII [4] is to provide adaptive user interfaces for persons with disabilities, in order to make all kinds of electronic devices and services accessible whenever and wherever they are needed. Aiming this, a cloud based infrastructure was built in order to transfer platform independent user preferences from one device to another and to infer appropriate user interface settings.

The general control flow works as follows: In a first step a personal device like a PC or Smart Phone must be configured according to the user's needs. These initial and device specific settings are used to deduce a platform independent user preference set. This preference set can be transferred to any other target device, either by a cloud service or by portable devices such as flash drives.

Due to the global availability of this preference set, any target device connected to the GPII can be customized to any user. Therefore, users can approach and log in to a target device of their interest. (e.g., ticket machine, PC in a public library).

Upon the authentication of the user, the target device contacts a service called matchmaker (local or cloud based) that is inferring the probably best fitting user interface settings for the user. Thereby it takes the user's preference set as well as a target device specific profile into account. The latter should include all available technologies on the target device that might help to assist the user in operating it.

In a final step, the proposed settings are sent from the matchmaker to a setting-handler being responsible for configuring and adjusting the target device to the user.

B. *MyUI framework*

With MyUI, Peissner et al. [17] present a framework to generate a wide range of user interfaces based on multimodal design patterns. It is designed to support runtime adaptations of the user interface aligned to the users' needs and preferences, characteristics and interaction capabilities of the used devices and conditions in the current environment. The process the MyUI runtime implements to create individualized user interfaces is separated into three steps (see Figure 1).

The first step is the user interface parametrization. For that, MyUI employs a mechanism to derive required user interface characteristics based on an existing context of use. The characteristics comprised in the resulting user interface profile include, but are not limited to information on screen complexity, layout structures, audio settings and navigation mechanisms. The user interface parametrization process is triggered each time changes to the underlying context information are detected to derive required runtime adaptations of the user interface. It is performed at least once when a certain user is recognized accessing the system.

The second step is the user interface preparation. MyUI aims at supporting adjustments of presentation formats and modalities as well as more extensive adaptations of interaction mechanisms and navigation paths. To permit the latter, an abstract description of the intended user interface is required. For that purpose, MyUI defines a graphical description language called the Abstract Application Interaction Model (AAIM) as an extension of UML2 behavioural state machines [18]. The states of the state machine represent the states of the interaction between users and the application. For each such interaction state an interaction situation is assigned which represents a certain interaction purpose together with the associated interaction options. Each time the current state in the application's AAIM changes (e.g., due to the user's previous action), MyUI selects the interaction pattern realizing the corresponding interaction situation that matches the current user interface profile.

In the last step, MyUI generates the final user interface based on the selected interaction patterns for the current interaction state. The user interface generation is based on common web technologies. In consequence the generated user interface is presented by a web browser. When the user interface for a certain interaction state is generated repeatedly, the transition between the former version and the new one is managed by adaptation patterns to ensure transparency of and control over the adaptation process for the user.

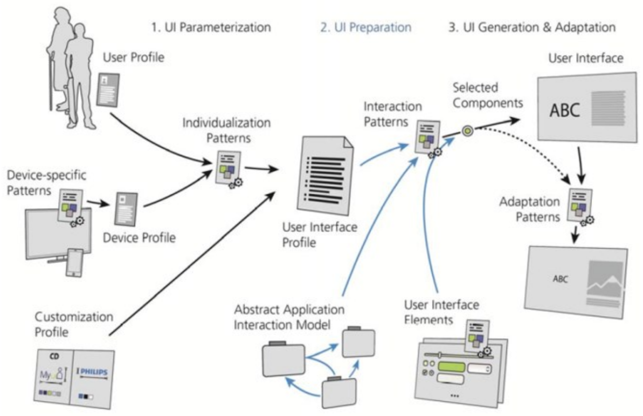


Figure 1. Overview of the MyUI generation and adaptation process [17]

C. *Assistive Technology Rapid Integration & Construction Set (AsTeRICS)*

Many people with disabilities worldwide are supported by assistive technologies [19] [20]. Assistive technology devices however often require individual adaptations, as they have been designed for explicit applications in specific environments. In this respect, routine activities of people with disabilities may be restricted, either because assistive technology devices cannot be adapted based on their needs, or because adaptations are too costly.

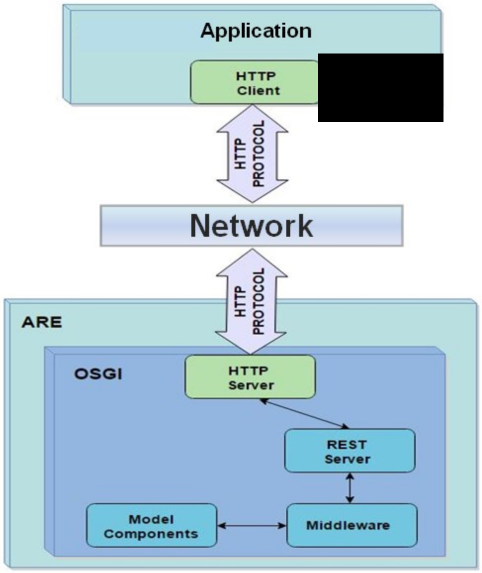
The AsTeRICS (Assistive Technology Rapid Integration & Construction Set) project [6] has built a hardware and software framework,that aims to reduce the time, effort and costs of developing assistive technology applications. It offers a flexible and affordable components set that enables building assistive functionalities, which can be highly adapted to the dynamically changing needs of each individual. The system is scalable, extensible and allows easy integration of new functionalities without major changes. It enables people with disabilities to gain access to the standard desktop computer, as well as to embedded devices and mobile services with no specialised user interfaces until present.

AsTeRICS provides the ability to define models, i.e., containers holding information describing the components that produce a specific assistive technology solution and their intercommunication (see Model Components in Figure 2). The components of a model can be classified into three categories: *sensors*, *processors* and *actuators*. Sensors monitor the environment and transmit input information to the rest of the model components. Processors are responsible for receiving, processing and forwarding this information. Finally, actuators receive data and carry out accordingly the desired actions.

AsTeRICS is constituted by two main components. The Web-enabled AsTeRICS Configuration Suite (WebACS), a graphical tool for creating assistive technology AsTeRICS models, and the AsTeRICS Runtime Environment (ARE) responsible for the deployment and runtime execution of the models (see Figure 2). The two components interact via the internet through a Representational State Transfer (REST) API on the AsTeRICS Runtime Environment. TheAsTeRICS Configuration Suite as well as the AsTeRICS Runtime Environment, were initially developed to communicate by using a proprietary protocol named ASAPI (**As**TeRICS **A**pplication **P**rogramming **I**nterface), which was not ideal because of the difficulty and complexity in learning and using. Instead, the REST protocol is easy to use and potential clients can easily adopt it for communication with the AsTeRICS Runtime Environment. The AsTeRICS Configuration Suite is currently under development in order to become web-enabled.

In this paper, we focus on the AsTeRICS Runtime Environment. The AsTeRICS Runtime Environment is a Java OSGi-based [21] middleware. The AsTeRICS framework offers a models@runtime approach, since the AsTeRICS Configuration Suite communicates with the AsTeRICS Runtime Environment to deploy the models and handle them at runtime. The AsTeRICS Runtime Environment enables the communication between OSGi bundles at runtime, which refers to the interactions and exchange of data between the sensor, processor and actuator components. Figure 2 presents the abstract view of AsTeRICS' architecture. The communication between the AsTeRICS Runtime Environment and potential assistive technology applications is conducted via the REST API [22].

The main requirement for making the AsTeRICS Runtime Environment RESTful was to provide remote access to its capabilities regarding integrating the very large set of AT functionalities offered by the implemented components into existing applications. In specific, the REST API offers platform and language independence, meaning that developers of the AsTeRICS Runtime Environment are able to reuse and integrate assistive technology functions into existing software applications without any concerns about the language and/or the platform used to implement and deploy the applications.



[redacted]

Figure 2. The REST-enabled AsTeRICS architecture.

D. Universal Remote Console (URC)

ISO/IEC 24752 [23] specifies the URC framework. The framework defines a mechanism for providing exchangeable and personalized user interfaces for all kind of electronic devices and services (so called “targets”). Thereby, user interfaces can range from pure software user interfaces to specialized hardware devices.

To enable exchangeable user interfaces, every target must provide an abstract description of its operational interface – the user interface socket description (or short “socket description”). This description contains information about variables that represent the target’s internal state, commands that can be sent by controllers to the target and notifications that are sent the other way round.

Furthermore, for every element contained in a socket description additional resources like labels in different languages, help texts etc. can be defined. Moreover, additional resources are not limited in their complexity and diversity. Just to give some examples, a resource can also be a video in sign language, help texts or a whole user interface being related to one or several sockets, targeting a special user group.

Additional resources can either be stored locally on the target or on a dedicated resource server. The resource server provides third parties like user interface or assistive technology experts the possibility to make their own contributions to a target’s user interface.

At runtime, any controller can connect to a target, read its socket description and download related resources from the resource server according to the user’s needs and preferences to render a personalized user interface.

In order to make the principles of the URC framework applicable to non-standard compliant devices, the Universal Control Hub (UCH) [24] was developed. This middleware solution can connect to various targets via target adapters and download the related socket descriptions from the resource server. Socket descriptions are no more exposed by the targets themselves, but by the UCH, serving as central access point giving controllers a transparent view on them.

Figure 3. Universal Remote Console Infrastructure

Hence, controllers can connect to the UCH and use it as mediator to access all connected targets via a standardized way by using the URC-HTTP protocol [25]. The received messages are forwarded to connected targets by dedicated target adapters. The UCH can overcome interoperability problems by loading/using different target adapters. The UCH and all related components are shown in Figure 3.

E. Summary

Summing up, the four described technologies can contribute to a solution that enables the control of various devices and services via an adaptive user interface. Even more, the adaptive user interface can be provided wherever the user needs it. Doing so, the following advantages are gained: GPII is used to offer a platform independent user preference set to any location/environment wherever an adaptive user interface is needed *(gu)*. The adaptive user interface layer is formed by the AsTeRICS and/or the MyUI runtime by taking the user’s needs and preferences into account. MyUI ships with its own real time adaptation engine to render an Abstract Interaction Model into a concrete user interface. Due to the concept of the Abstract Interaction Model the requirements of abstract interaction *(ia)* and abstract task descriptions *(ta)* are satisfied. Also, the usage of different AsTeRICS models contributes to *(ia).*

The two runtimes can then connect to the UCH that serves as central access point for controlling various distant devices and services. The concept of socket descriptions gives a transparent view on the connected targets *(da)* and different target adapters help to overcome interoperability problems. Furthermore, the UCH also connects to a dedicated resource server in order to provide user interface components for the technologies forming the user interface layer *(gr)*.

V. INTEGRATION AND PROTOTYPE IMPLEMENTATION

Since all the four frameworks GPII, AsTeRICS, MyUI and URC were originally developed independently from each other, a decision was made to look for a very lightweight and flexible way of integration. This gives system developers the freedom of choice concerning the frameworks they want to use, not limiting them in using one very complex monolithic system. Furthermore, for research purposes and considering also the further independent development of the four frameworks, a lightweight integration bears many advantages. A lightweight integration is also most in line with the GPII and Prosperity4all philosophy of having a set of independent components from which IT developers can choose.

In the current prototype, URC socket descriptions are used to satisfy the requirement of an abstract device layer *(da)*. Socket Descriptions and all connected targets can be accessed via the UCH that serves as central access point for any user interface.

The user interface layer is formed by the MyUI and, potentially by the AsTeRICS frameworks.

Concerning the communication between the user interface layer and the UCH, two cases can be distinguished. Either AsTeRICS or MyUIare used on their own to communicate directly with the UCH via the URC-HTTP protocol or AsTeRICS and MyUI are doing so cooperatively.

If an application needs to benefit both from the adaptive graphical user interface of MyUI, as well as from the various configuration possibilities provided by the AT-enabled input/output devices of AsTeRICS, both frameworks can be used in conjunction. In this case, MyUI communicates with the UCH via the URC-HTTP Protocol, while AsTeRICS and MyUI communicate via the operating system (OS) layer (see Figure 4). In specific, MyUI is used to provide users with an adaptive graphical user interface while AsTeRICS is used to control this graphical user interface by user specific input/output AT-enabled modalities (e.g., controlling the mouse via head movements, an AT functionality necessary for people with limited or no hand movement).

If AsTeRICS is used in cooperation with MyUI, the choice of which AsTeRICS model to use may depend only on the user preference set. This is due to the fact that the AsTeRICS task in this scenario is limited in controlling the MyUI graphical user interface, as well as perform other assistive technology enabled functionality (depending on the active model), while the coordination of interacting with URC targets is being conducted by MyUI (scenario 2, Figure 5).

More precisely, the coordination of tasks is specified in an Abstract Application Interaction Model. The choice of which model to select depends on the targets being currently connected to the UCH. The different Abstract Application Interaction Models available at a certain moment are provided by the UCH that downloads them from the URC resource server. The selected model is rendered by the MyUI adaptation engine into a real graphical user interface. The conducted adaptations are based on the information contained in the user preference set provided by the GPII. If special Input/Output modalities are required, the user preference set is also the resource that is used to specify certain needed AsTeRICS model characteristics that determine which AT models to be loaded on the AsTeRICS Runtime Environment from the resource server.

In case AsTeRICS is used on its own (no direct communication with MyUI), the selection of which AsTeRICS model to load depends not only on the user's preferences, but also on the targets available via the UCH, since AsTeRICS needs also to communicate with and control URC sensors/actuators (scenario 1, Figure 5).

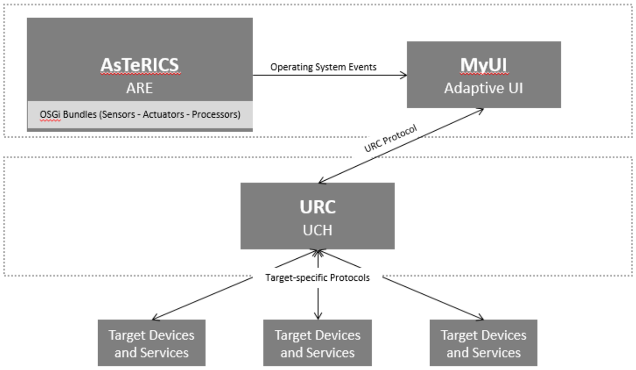


Figure 4: An application uses the MyUI adaptive graphical user interface and the AT-enabled devices of AsTeRICS: MyUI communicates with UCH via URC-HTTP Protocol; AsTeRICS and MyUI communicate via OS layer

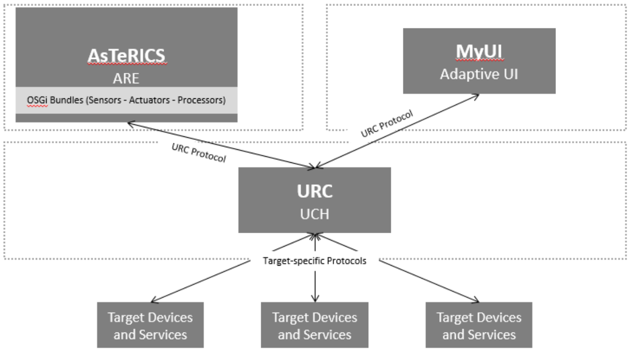


Figure 5: AsTeRICS without direct communication with MyUI: needs also to communicate with and control URC sensors/actuators

An important issue to consider is that the requirements of an abstract device overarching task description *(ta)* and the one of an abstract interaction description *(ia)* are only fulfilled by making use of the MyUI engine and theAbstract Application Interaction Model. The latter can be used to specify a sequence of function calls to different targets and with that the execution of tasks.

VI. DISCUSSION AND OPEN RESEARCH QUESTIONS

Although the current prototype provides an adaptive user interface layer, there is space for further improvements, mainly to the continuity of the adaptation process. At this stage, the system provides only in some parts a continuous adaptive user interface, while in others only initial adaptivity is supported. Due to the continuous monitoring of the user and other connected sensors, the MyUI interface provides mechanisms for continuous adaptations. This is different for the user interface parts that are related to the AsTeRICS runtime. At this stage, AT model loading is specified by the user's preference set and there is no feedback mechanism that could be used by the MyUI engine to refine the parameters being set within the loaded AsTeRICS model, i.e., on model component level. MyUI, as with any other application, can interact with the AsTeRICS Runtime Environment via the REST API only on model management level, i.e. determine which model to start, stop, pause, etc., but not on model component level, e.g., which sensors to use within a model.

Furthermore, based on user needs and preferences, only one predefined AsTeRICS model can be loaded. This requires that the related hardware components are always available on the target system. If this is not the case, there is no alternative model to be loaded. Hence, a prioritized list of alternative AsTeRICS AT models for a particular set of user needs and preferences could be specified as a future improvement. Even more interesting would be to investigate whether it would be possible to use a GPII matchmaker instance to infer parameters or even a whole AsTeRICS model by taking a user preference set into account.

More importantly, there is the need for an appropriate security mechanism that protects the system from malware injection. Since any third party can contribute its solutions and make them available via the Resource Server, there is always the risk of introducing malware. To cope with such issues, one could think about a review process for resources, as it is known from some app stores for mobile applications. The current implementation is lacking such techniques and also GPII itself is still requiring an appropriate security framework.

Next, there is the need for appropriate user interface development tools. At this moment there are tools available to create URC sockets as well as tools to create MyUIAbstract Application Interaction Models. However, this can be done only separately. All in all, there is a need to define a development process for adaptive user interfaces that coordinate different target devices. It is not yet clear how such a process will look like, but it is for sure that future development tools need to provide a tighter integration between the abstract target descriptions and the abstract task descriptions.

Finally, appropriate testing needs to be conducted. We plan to test the proposed integrated prototype by using real users in real environments. The aim will be to address their real needs in terms of accessibility, assistive technologies and smart interfaces.

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