Accessible Display Design to Control Home Area Networks

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**Abstract — ***Recently, the social inclusion and technical aid to assure autonomy to people with disabilities are getting attention all over the world. This work presents a display design for accessible interaction in home area networks. Based on a research on the accessible interfaces state of the art, an interface design was proposed. This interface was implemented over a Tablet that controls domestic devices through a home network controller prototype. In order to evaluate the design, a research was conducted, interviewing people with disabilities in Brazil. This research consolidated a feasible accessible interface to control home area networks pointing out the main requirements considering a diversified group of impairments.*[1]

Index Terms — home automation, user interface, universal design, accessibility.

I. Introduction

Focusing on the use of home area networks to improve disabled people's autonomy at home, this paper presents a display design for accessible home control.

In the past years, computational devices have turned faster, smaller, connected and cheaper. It brings the "intelligent house" vision, promised for decades, closer to reality. This pervasive, intelligent home, a luxury item for many people, could have a key role in assuring the autonomy of people with disabilities.

In Brazil, assistive resources and their use are relatively recent as compared to the United States, for example, where specific laws were established in 1988. In Brazil, similar regulations have existed since 2004 and establish general standards and basic criteria to promote accessibility. [1]

Thinking about users with disabilities, it is necessary to invest efforts in the research and development of accessible interfaces, through the perspective of a universal design that is easy to use and to learn how to use. The design for all, also called universal design, began focusing on physical aspects (buildings, urban spaces, transport, health, leisure), and nowadays is extended to the digital world (computer networks and communication systems). In this perspective, accessibility is defined as "a condition for autonomous and safe use of space, furniture and urban facilities, buildings, transport services and devices, systems and media and information by people with disabilities or reduced mobility." [2]. It is worth stressing that accessibility is not the creation of exclusive spaces for people with disabilities, which could be a form of discrimination, but rather of thinking of systems and environments, which can be used by everyone.

The work was developed starting with an interface design proposal, based on the research on accessible interfaces state of the art. The interface was deployed targeting Tablets and Smart Phones interoperability. It was integrated to control a home gateway prototype. In order to evaluate the design, ten interviews with people with disabilities were conducted in Brazil.

This research could consolidate a feasible interface to control home area networks pointing out the main requirements for home area networks considering a diversified group of impairments. This paper is an extended contribution to the work [3].

II. Related Work

Analyzing the state of the art, it is possible to notice that the works on user interface for home automation for people disabilities are very specific, usually addressing a single type of impairment. There are works focusing on elderlies, visually impaired people, hearing impaired, people with motor impairment and cognitive disabilities.

The project Assistive Housing [4] was developed focusing on the elderly comfort, allowing home automation by using the television set and its regular remote control as an interface. The design strategy used to improve legibility and accessibility of the home automation interface on the television screen was to use few and large graphical icons, with horizontal captions describing their function. Figure 1 presents a menu screen shot as an example. The interaction is made through numbers, as shortcuts, avoiding navigation with keys. The idea of having a clean design, with few and large icons and the use of a consumer electronics appliance that is already familiar to the user will be exploited in our work.

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In addition to the interface design, this work presents the solution to implement home automation and a sensor network to acquire context and to identify emergency situations. This project relies on power line communications and on the OSGi framework usage.

Fig. 1. Assistive housing project menu screen [3]. This Figure shows the automation menu screen on a television set, with selection through remote control number keys.

There are two other relevant projects to monitor elderly using sensor networks and integrating home automation, but they do not explore user interface design [5], [6].

In Mainardi's work [7], the project is designed for people with manual dexterity and mobility impairments, but it could be widely used. The idea is to have a portable touchscreen device with the proposed interface. The first menu the user has to deal with – shown in Figure 2 – represents all the rooms of an apartment.

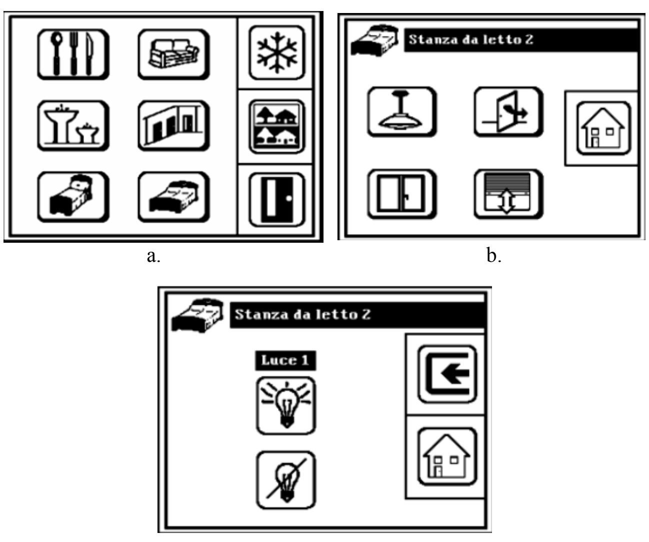

Fig. 2. Three screens of a home automation interface, each one representing a different level of the interface [6]. Screen "a" presents icons representing the rooms, screen "b" presents icons with the items to be controlled, and screen "c" presents the commands available.

When a room is selected, a new screen is presented containing all the items available to control in that room. In order to inform which room is selected at the moment (specially important to people with cognitive problems), the icon that represents the room is shown at the top of the screen, while on the right side of it is a "home" icon, that allows the user to come back to the main menu.

When an item is selected, a third and last menu level will appear showing the commands available. The icon of the selected room is maintained at the top of the screen, and the icon of the item being controlled is also presented. On the right side of the command screen, two icons are presented: the back icon at the top, that allows the user to go back to the previous level, and the home icon at the bottom, that allows going to the main menu.

The concept of using different levels of screens containing icons representing the rooms, the appliances to be controlled and the commands was utilized in our work, but as it is intended to be universal, additional requirements were needed.

Another work presented the use of touchscreen devices combined with voice control, allowing the interaction of people with limitations in their upper and/or lower limbs, replacing the standard devices (mouse and keyboard) [8].

The voice control systems in the state of the art are suitable for interactions with menu screens. Some works present systems based on a hardware-software co-design that allows speaker-independent speech recognition at an accuracy rate of 95%, without voice training [9]. This interface was tested in a home automation environment using a ZigBee-based wireless sensors and actuators network.

Other works present solutions of image processing for interacting without traditional interaction. A gesture-based control system was developed to simplify the home automation interaction to people with mobility impairments in the Intelligent Sweet Home project [10]. This system is able to control various home appliances with hand gestures. The user selects the device to be controlled by pointing it with the hand. The command operation is executed via a predefined hand gesture. The system works with real time video images processing. Another solution was developed to replace hand interaction using head movements and mouth position [11]. Through serial communication and infrared, the system controls appliances.

III. Interface Design

This work target users are people with visual, hearing, motor and cognitive disabilities. In order to develop a widespread and easy-to-use interface, a design approach based on icons was adopted, quadrants and touch screen combined with voice control.

The touchscreen choice was made based on three factors: the widespread use of this technology on mobile devices, the touchscreen intuitiveness and the possibility to include people with upper limbs impairments [7]. Considering that people with disabilities have more locomotion difficulty, the possibility to have the home control interface on a portable device such as a smartphone or a tablet is an extra advantage.

The adopted design is based on quadrants to achieve a universal user interface for home network control. The quadrant design had been previously used by Zhao et al. to deploy GUI to visually impaired users [12]. Although the quadrants design in Zhao et al. work showed not to be the best design solution for visually impaired persons, it proved to be suitable to them. This work hypothesis was that the quadrant approach is a good design considering a wider variety of impairments, allowing fast learning and intuitive use.

In the design, the quadrant approach was used, considering a layout with five buttons occupying the whole screen area. There is one button in each quadrant (four buttons) and one (the fifth) in the center of the screen. In order to improve the interface intuitiveness, a text label, an icon, and a color were associated to each button. An example of this approach can be seen in Figure 3.

The screens map considers three menu levels: rooms, appliances (items to be controlled) and commands. This approach is intuitive, having a fast learning process [6]. At each level, the information on the last levels selection is presented. When a room is selected, its icon is presented at the top of the device list menu. When the device is selected, both the room and the device are presented on the screen.

Fig. 3. Main menu screen. This Figure shows the main menu screen as the quadrant approach design example. It presents the menu with four virtual buttons, one in each quadrant. Each button has a different color, an icon and a label, representing one room of the house. The center button activates voice control.

The interaction mechanism was based on "touch" and "hold pressed" events. The "touch" event selects the key and a "hold pressed" event triggers the action related to the key. The action could be to send a command or to go to a next screen in the interface.

Both events generate visual and audible feedbacks. The "touch event" generates the synthetized locution of the touched key text label as audible feedback; the visual feedback is provided by the key enhancement by changing its brightness. The "hold pressed event" generates the synthetized locution of the name of the next screen as audible feedback, or the new status of a device (if it is related to an action command); the visual feedback occurs by changing the screen to the next one or representing the new status of a device, if that is the case.

The interface proposed also has another interaction mechanism that uses speech control. The user can say the name of any screen or key in order to trigger an action. Although our proof of concept has only one speech option to each command, it is possible and necessary to register similar or equivalent commands, in order to facilitate the voice interaction mechanism. The central button on the main menu screen activates the speech control mode.

The device that embeds the interface has keys that are used by the interface as well. These keys are for optional usage. The BACK key opens the main menu screen, no matter on which screen the interface is. The MENU key presents the configuration screen. It allows configurations related to the touch event and hold pressed event time threshold, to the speed and voice of the synthetized speech, etc.

IV. Implementation

The interface was implemented over a Tablet with 7-inch display, 512MB of memory and a 1GHz processor. The interface implementation consists of thirteen screens with five devices and lighting being controlled. Figure 5 presents the screen tree of our proof of concept implementation.

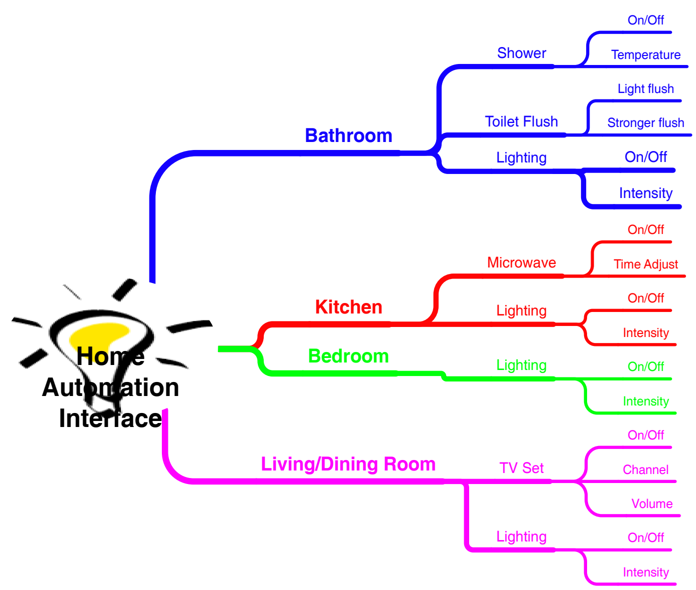

Fig. 4. Screen navigation map. This Figure shows the designed screens and the navigation possibilities through them. The item selection and its controls were implemented just as an example to test the interface design elements.

The interface consistency was maintained, using the quadrant layout approach to every screen. In the first screen (main menu), the quadrant keys are used to select a place in the house and the center key is used to activate the voice command mode. In the next screens, the quadrant keys are used to select the devices that will be controlled and the center key to go back to the last screen. Selecting a device, the quadrant keys send actions to the device, and the center button goes back to the last screen. The MENU key has not been implemented yet, not allowing configurations by users.

In order to integrate this interface with a home automation system, a development board with an embedded microcontroller was used. The interconnection between the tablet and the automation system was made using a Bluetooth connection that is currently available in most tablet models. A commercial Bluetooth module was used connected to the development board in order to execute the experiment.

In our tests, the development board was used to control lighting, air conditioner and a TV set. The interface design has other devices that were not implemented, providing a conceptual design.

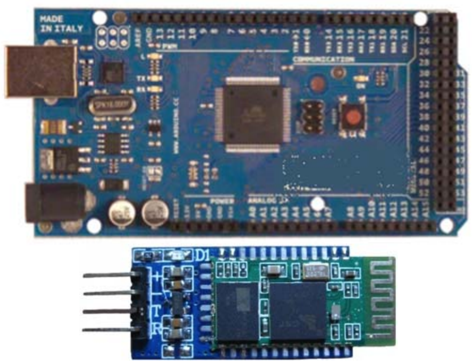

Fig. 5. This Figure presents a picture of the development board and its Bluetooth daughter board.

V. Design Evaluation

The development cycle of our prototype included usability evaluations by users. Usability of a product is analyzed by considering user satisfaction in an approach that values your expectation and experience of use [13] [14]. Products developed without usability requirements can cause poor performance and a reduction in quality of product for users [15] [16].

Design methodology chosen to usability evaluation was Empirical Usability Method with participation of users [17]. In this method, real users perform tasks with the product while being observed by evaluators. Therefore, it is important to review the test conditions, making sure they are the same for all participants. Among the objectives of this method, are: predict usability problems such as learning difficulties and run-time task in the operation with the product; diagnose what may be inconsistent with the standards implicit and explicit usability; see, observe and record usability problems during interaction with the product; calculate objective metrics for effectiveness, efficiency and user productivity through interaction with the product; know opinion of user about product; suggest priorities for solving usability problems based on the test results [16], [17].

For data collection, it was considered the most appropriate Test Prospective technique [18], [19]. This technique is characterized by interviews and questionnaires in a parcel of real users before and after using the product. The objective was, through this technique, to collect information about the experiences, opinions and preferences of users that interacted with the prototype.

To select sample, a non-probability sampling technique was used; this technique are characterized by not including all individuals in the study population [20]. The purposeful sampling [21] was used, which selects individuals that have a characteristic of specific interest to this research. Main selection criterion was users have some form of disability. People with different types of disabilities were selected. That's because all usability requirements of interface could be tested and validated.

Ten users were selected: 03 blind, 01 deaf, 01 wheel chair user, 01 motor-impaired, 02 elderly and 02 cognitive-impaired. Furthermore, users needed to have basic knowledge in informatics.

The reason for a small number of users is primarily the availability of participation and also logistical limitations (only one tablet for testing). However, small number of users allowed a more personalized experience, revealing some factors that could only be verified through observation and qualitative analysis. Other usability evaluation researches also used small samples [22], [23] which were obtained good results against goals expected. Another justification comes from Jacob Nielsen [24], a leading researcher in usability evaluation. Nielsen says that a single user can find around 30% of usability problems in an interface. According to Nielsen, from five users, increasing the number of users does not correspond to a significant gain. Also according to Nielsen, percentage of usability errors found by a group composed by five users is 85%, which represents the best cost-benefit.

The short test period was considered appropriate to evaluation because the prototype quadrant could be considered widely explored and were consistent with the design methodology chosen.

A closed questionnaire was created. It was divided into two parts: pre-test and post-test. In pre-test, a set of questions was asked to participants before start of testing for interaction with product. It aimed to determine the profile of participant: age, gender, type of disability, level of technical knowledge (computer, smart phone and tablet), level of knowledge about home networking and home automation. At post-test, the participants answered questions about their motivation, satisfaction and level of knowledge gained from using the product.

TABLE I
Likert Answers – Post-test Questionnaire

( ) Very Good	( ) Good	( ) Neutral	( ) Poor	( ) Very Poor

Answer options consisting of a grading scale based on Likert [25] ranging from Very Good and Very Poor. Likert scale is based on a statement where the respondent shows degree of agreement / disagreement, employed in research consists of closed questionnaires. This scale has become a paradigm of qualitative measurement and has since been widely applied, either in original form or in adaptations to different objects of study [26], [27], [28]. In our questionnaire, for each question, users responded that degree represents your prototype evaluation in terms of "Very Good", "Good", "Neutral", "Poor" and "Very Poor". This type of response was considered pertinent to this research because highlight extremely positive, negative and irrelevant answers about interaction with product. Table I presents the alternatives post-test questionnaire.

The interviews were dived in two phases. First, the concepts of home networking and home automation were presented and data about the individual were collected by the pre-test questionnaire. The second phase of the interview was directly related to the Interface evaluation. Firstly, the interface was presented and was showed to them how to use it. Secondly, the interviewees could play with it for some minutes. Thirdly, some challenges were presented (turning off the kitchen lamp, for example). Finally, the post-test questionnaire was filled, related to the feedback concerning many aspects of the interface.

Evaluation was conducted with users in EFORT Institute where are people with disabilities. This institute is located in São Paulo City. Tests with users lasted an average of 50 minutes each, totaling eight hours spread over two days. Parents accompanied users with cognitive disabilities. For communication with people with hearing disabilities, a sign language translator provided assistance.

With the interviews, the quadrant approach design has shown that it could successfully lead to a universal design. The users evaluated the interface positively. In all the criteria (easy to use, layout and subservience) the interface got 80% of the interviewees' highest score. In addition, most users could meet the proposed challenges after a short learning time (up to 5 minutes).

The blind people faced some challenges with the tablets boarding that is the non-functional glass area around the screen. Our model had around 1 centimeter boarding around the displaying area, where the touchscreen was out of range. Despite this issue, the interviewees were able to learn the appropriate distance and to use the quadrant approach. It was possible to conclude that the ideal touchscreen interface to this implementation would be the one with the tiniest boarder.

Another consistent feedback from the blind people was the requirement to configure the screen reading speed that, despite having been designed, was not implemented at that moment.

TABLE II
PERCEIVED VALUE ON AUTOMATION

Items	Perceived Value
Lighting	**3.3**
Security (gate, door, alarm system, cameras, etc.)	3.6
Laundry machine (washing and drying)	2.4
Air conditioning / Heating system	2.9
Shower temperature	3.1
Security sensors (gas, smoke, etc.)	3.6
Energy consumption management	3.3
Water consumption management	3.3
Sound system	2.9
Home theater and television	3.1
Dish washer	1.5

Scores semantics: 0 is not important at all and score 4 means that this item automation is highly important.

Regarding the perceived importance of the home networking deployment at home in order to achieve autonomy and comfort, a list of items to be potentially automatized was presented and the interviewees gave a score of integer values from 0 up to 4 to each one. Score 0 means that this item automation is not important at all and, conversely, score 4 represents that the item automation is highly important. The average values of the interview results are summarized in Table II.

All of the interviewees were noticed to consider safety aspects of high importance. As safety aspects were included in our questionnaire: security camera monitoring and control, house gate opening and closing, alarm setting, fire and gas sensors.

As a second degree of perceived importance, but still very desirable, are the technological aids for saving natural resources. In this category are energy and water saving technologies, for example. Leveraged by the smart grid trend, many products to measure the home appliances consumption and energy consumption management systems are already being deployed. The electrical energy and water home consumption management systems, integrated to home automation, showed a high perceived valued by the interviewees.

VI. CONCLUSIONS

Despite working with a considerably varied group of users, with different needs, an interface suitable to them was achieved. Our interface integrates accessible interface ideas in a single portable interface that can contribute to people with disabilities' autonomy at home.

Despite being a potential solution to improve the autonomy of people with impairments, the interviews have shown that home automation is not even considered as a possible solution to these people's reality. They consider home automation a high technology solution out of their reach. It points out to the demand for researching and developing lower cost and simpler solutions.

As the next steps to this research are the improvements of the interface with the interviewees' feedback, to integrate the new explore-by-touch features available in the new tablets' operating systems libraries and the repetition of the described experiments with larger groups of users.

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