Home Automation for an Independent Living: Investigating the Needs of Visually Impaired People

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ABSTRACT
Independence is essential for everyone and crucial for people with disabilities. Being able to perform the activities of daily living as autonomously as possible is an important step towards real inclusion and an independent life. Several technology-enhanced services and tools have been created to address special-needs users, but are they really used and appreciated by them? Sensors and radio frequency devices are increasingly exploited to develop solutions such as the smart home, aimed at improving the quality of life for all, including people with visual impairment. This paper collects blind users' expectations and habits regarding home automation technology through an online survey and face-to-face interviews. Specifically, 42 visually impaired people answered an accessible online questionnaire to provide more insight into their needs and preferences. Next, semi-structured short interviews conducted with a set of eight totally blind participants enabled the collection of relevant user requirements in order to better understand the obstacles experienced, and to design usable home automation and remote control systems. Results showed that the main requests regard increasing autonomy in everyday tasks and having more usability and flexibility when using remote home automation control. Thanks to the collected feedback, a set of general suggestions for designers and developers of home automation and remote control systems has been proposed in order to enhance accessibility and usability for the blind user.

CCS Concepts
• Human-centered computing~Empirical studies in accessibility • Social and professional topics~People with disabilities

Keywords
Home Automation; Blind users; users' survey

1. INTRODUCTION
Recent technology has offered new scenarios for enhancing everyone's quality of life. Especially for people with disabilities, having truly accessible services and tools can significantly change their level of independence in their studies, work, free time and at home.

Today, thanks to the Internet network, sensors and smart objects/devices can communicate with each other (Internet of Things) and trigger customized and contextualized services. Many commercial solutions are modular and can easily be plugged in, as expandable systems. Personalization is usually applied to address specific user needs, but the configuration process can be difficult for totally blind and unskilled users.

Actually, simple tasks can also be difficult or even impossible for a blind person to perform if products and everyday objects are complicated to use or have poor accessibility. Fortunately, ICT can simplify those complex tasks, if an appropriate design methodology is applied. Taking into account users' needs and expectations can be a valuable starting point for implementing an accessible design methodology. Several steps such as incorporating basic accessible functions as default parameters, organizing simple and clear interfaces, optimizing content navigation, managing the interface focus and delivering object semantics to the screen reader, and so on, can contribute to accessible design.

This paper investigates blind people's habits, preferences and wishes concerning their independence in daily life at home.

Several accessible tools have been specifically developed to allow blind people to carry out routine activities. However, various tasks are still inaccessible or have limited usability because the technology is not yet completely mature or the accessible products are too expensive. Universal design might be a valuable support in overcoming such inconveniences. Home Automation Systems (HAS) is a very valuable tool for making home activities truly accessible to blind and low-vision users, provided the user interfaces and the services offered are not only accessible but especially usable.

Several devices and apps are available nowadays on the market to support daily life at home for visually impaired people. Are they really accessible and effectively used by people? Do they resolve all the issues encountered by a blind user or are some ICT solutions still lacking for daily independence? Answers to these questions can be useful for designers and developers when collecting information for creating powerful new solutions. Specifically, understanding the habits and expectations of the visually impaired can contribute to making Home Automation Systems and Remote Control Systems (RCSs) more usable for all.

To this aim, we recruited a group of blind and visually impaired users who filled out an online questionnaire. The survey was complemented with semi-structured interviews with a

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homogeneous sub-group of totally blind individuals, corresponding to one-third of the total users surveyed.

The main contribution of this work is (1) a report on needs, expectations and concerns related to technology as a support for independent daily life at home for blind people, and (2) an initial set of guidelines for designers and developers of home automation systems accessible to visually impaired users.

The paper is organized into seven sections. Section 2 introduces the related work and Section 3 describes the study. Results are introduced in Section 4 and a discussion highlighting possible research directions is reported in Section 5. In Section 6 recommendations and suggestions for designers are proposed. Conclusions and future work end the paper.

2. Related Work

The last decade has seen many advances in the Internet of Things. Smart devices and sensors, wearable personal health systems, and RFID readers/tags contribute to creating a smart object ecosystem. The object has a unique identifier that provides its identity. Thanks to the network's infrastructure, object-to-object communication is possible. For instance, context-dependent services can be activated based on user position or on his/her proximity to smart objects.

Several studies have investigated how to exploit information and communication technology (ICT) in order to assist people, and specifically how to design Ambient Assisting Living (AAL) systems for monitoring and enhancing the independence of people with disabilities. Aging may progressively lead from low to severe degrees of disability. Often old persons have multiple disabilities, involving both the perceptive and cognitive systems. The European Community funded a focused AAL Program with the goal of creating better conditions of life for the elderly and fueling the ICT industry. By analyzing current research and practices, and highlighting technical and social challenges, future research directions have been discussed in [1].

The Internet has led to simpler and smarter home automation, accessible anytime, anywhere, enabling smart houses. Smart houses are very valuable for people with disabilities since they offer the opportunity to achieve independence. This encompasses not only usability but embraces personal care and safety.

Recent advances in wearable health monitoring systems enable early intervention, which can contribute to increasing life expectancy [13]: body area networks and Health Smart Homes (HSHs) incorporate wearable as well as fixed health systems to assist elderly or disabled people [9]. Personal monitoring systems are essential for early intervention, and to prolong life expectancy [13]. Wearable smart devices are able to actively and steadily monitor vital parameters (body area networks). However, a recent systematic review of smart homes and home health monitoring technologies point out that the technology-readiness level for these systems is still low and lacks strong evidence for their effectiveness as a prevention tool assisting the elderly population [8].

B-Live is an example of a system designed for the motor-impaired (tetraplegic, paraplegic, wheelchairs users) and the elderly, aimed at assisting people in common tasks, such as turning room lights on/off, or opening/closing shutters and doors [12]. Among natural forms of interaction with technology, voice and feel are increasingly emerging. The acceptability of vocal interaction in smart homes with elderly people living alone has been investigated by [10]. Authors observed that speech technology has a great potential to ease everyday life but encourages a lazy lifestyle, provoking rapid degeneration of health in old persons. This study indicates that when designing for the elderly it is crucial to promote a healthy way of living [10]. Pervasive mobile technology plays a fundamental role in the remote control of old people, especially when relatives are involved in their social integration and physical stimulation.

Several solutions have been designed to help blind people in everyday life [2]. For instance, a system for object recognition that exploits social contributions has been created to help the blind in everyday life (VizWiz Social). Concerning home automation and remote control systems, in the last decade low-cost smart systems have emerged: 1) low-cost open built-in solutions, such as Fibaro[1] or 2) solutions taking advantage of Android (the popular mobile Operating System) and Arduino[2] (an open-source easy-to-use hardware and software platform). All these systems enable the remote control of home appliances and surveillance systems also via mobile devices, smartphone or tablet, in a simple and effective way thanks to a reliable, pervasive, high-performing network infrastructure. Unfortunately, accessibility for blind people is still neglected. For instance, the Web user interface of Fibaro, a popular Remote Control System (RCS) has been analyzed via screen reader, showing that the interface does not properly deliver information to the blind user [3].

Recently vocal assistants such as Alexa (Amazon) or Home (Google) have entered the market. Indeed, voice-based assistants can greatly enhance interaction for the blind user. The possibility of easily integrating IoT devices that exploit the vocal ability of these assistants can simplify interaction and open new avenues for blind people. Vocal assistants and smart speakers enable one to listen to music, ask questions, get news, and turn the lights on/off. Vocal commands can trigger specified actions (e.g., turn on/off, open/close). However more specific commands to check the device status such as "what lights are on?", or "Which shutters are open?" might require technical settings and customization that may be difficult for unskilled people and especially for sightless users. For a blind person asking for information about device status is equally important. To our knowledge, currently such a functionality is not supported enough by the virtual assistants available on the market. Moreover, considering that vocal interfaces could encourage a sedentary lifestyle, accessible interfaces via touch screen mobile devices are valuable for preventing possible health problems in the elderly [10]. Unfortunately, at the time of this study these home virtual assistants were unavailable in Italy, so participants were unable to evaluate them.

Technology-enhanced solutions designed for helping people with disabilities in smart houses are useful for anyone living under difficult physical or environmental conditions. Thus, the usability of eye-free design has potential for benefiting society as a whole. A phone-based interface in a home automation system has been tested by [8], showing that the introduction of no-speech sounds may improve user experience.

Progress in the IoT (Internet of Things) has led to improvement in multiple areas, including smart homes. Sensors and actuators can be embedded in artifacts, smart home appliances and furniture, and RFID systems to control access and improve safety. People with disabilities enjoy smart homes if accessible and usable interfaces enable easy and effective control of the home. Assistive devices enable participation in social activities while smart

[1] http://www.fibaro.com
[2] http://www.arduino.cc

sensors monitor their health conditions [2]. To offer alternatives to persons with disabilities for easy control of domestic appliances such as lights, Jeet et al. propose a multi-modal interface system driven by both voice and gesture commands to control distributed home appliances in smart homes, in order to permit hands-free operations to people with motor disability (quadriplegia). Nevertheless, blind people can also take advantage of multimodal interaction [7]. Indeed, sightless people need accessibility in everyday tasks as well as when using any domestic appliances such as ovens, washing machines, TVs, coffee machines and so on.

Most available studies on smart homes are devoted to the elderly, who generally have some degree of impairment in the perception (visual and hearing), motor and cognitive channels but there is only a small overlap with the needs of the blind population in general, who interact via screen reader and voice synthesizer. In this study we investigate these aspects.

3. The Study

3.1 Method

A participatory study was conducted with a group of visually impaired people in order to collect their difficulties and expectations with regards home automation. An electronic survey integrated with a meeting *de visu* with a representative set of participants enabled us to better understand their habits and expectations regarding autonomy in handling home automation and remote control systems.

Participants were contacted via email by one of the authors as personal contacts as well as on suggestion by the local Italian Association for the Blind. The users were asked to answer an anonymous short online survey concerning the tools used for handling home activities autonomously and their expectations about home remote control and automation systems.

Users were informed about the purpose of the study, data collection, processing and results publication, according to EU privacy legislation.

No compensation was provided for user participation, which was entirely voluntary.

3.1.1 The Questionnaire

To encourage user participation we decided to create a very short questionnaire. The effort of filling out an electronic survey for a blind person is usually much more time-consuming than for a sighted user, due to the screen reading interaction: sequential reading, focus management with active elements, stopping and continuing the reading, lack of accessible design or browser peculiarities could create a lot of difficulties or frustration. For these reasons a long survey with many questions might demotivate some potential participants and the rest may not be wholly representative of the visually impaired population.

The online questionnaire was created using Google Form, part of Google Drive, since it automatically analyzes collected data, immediately showing attractive graphics, and offers a good degree of accessibility via screen reader. The language was Italian since the survey was conducted in Italy.

The questionnaire included only 10 entries: 3 items to characterize the sample (age range, gender and visual disability), 5 closed questions (with an edit field for specifying or clarifying) regarding user habits and preferences, 1 open question for collecting expectations of desired functions (to be integrated in the home automation system) and last, 1 text box for suggestions, comments and requests. Only the answers that characterized the sample were mandatory.

Participation was high compared to long multipage surveys we had carried out previously, and we recruited 42 persons in a short time. To ensure the accessibility of the questionnaire, two totally blind users were involved to verify the questions' easy comprehension as well as rapid navigation and interaction via screen reader.

In summary, investigated aspects include:

(1) The hardware and software tools (if any) used by blind people to aid in autonomy at home
(2) The users' expectations with respect to remote control systems and Home Automation
(3) Suggestions and indications about potential functionalities and their arrangement, to be exploited in designing the user interface of a remote control application in order to improve its accessibility and usability via sightless interaction.

3.1.2 The Interviews

After collecting the user responses, one meeting in person was held with eight (i.e., 1/3 of the) totally-blind participants, who had previously filled in the online questionnaire, to obtain more information on the operative scenarios and everyday difficulties. All the users met at the seat of the local Association for the Blind, which had called them on our behalf. A semi-structured interview was applied introducing two main topics but leaving an opportunity for new ideas to emerge in a collaborative fashion. The aim of these interviews was twofold:

(1) to collect more details and opinions on commercial tools (especially those cited in the questionnaire), and their effective usage and limitations in daily life;
(2) to gather more information about the interest of totally blind people in automated control of home appliances such as lights, shutters, heat control and any other aspects related to Home Automation.

Overall, the meeting sessions lasted 2 hours. Participants were interviewed to facilitate the discussion and elicit answers.

3.2 Participants

Forty-two visually-impaired people participated in our study: 32 totally blind (i.e. 76.2%) and 10 low-vision people (23.8%), 15 females (35.7%) and 27 males (64.3%).

The age ranged from 18 years to more than 70 years and is well-distributed, as shown in Fig. 1. Age 18-29 years is represented by 6 persons, corresponding to 14.3% of the sample, the range 30-39 years by 10 participants (23.8%), the range 40-49 years comprised 9 users (21.4%), the range 50-59 is represented by 9 persons (23.8%), 60-69 by 6 participants (14.3%) while only 1 person (2.4%) represents the 70+ years range.

Participants' habits, needs and preferences on home automated and remote control systems were collected electronically. The interviews provided insight into popular commercial products for automating simple tasks and collected indications on the *modus operandi* of main control systems such as lighting and heating.

4. Results

All the participants answered the closed questions although they were not mandatory. The first question involved the preferences about remote-control interaction. Although mobile touchscreen devices still pose some challenges in a no-visual interaction, the smartphone was slightly preferred over the computer by the survey participants. However, most of them (more than half of

surveyed users) believe it is valuable to have both possibilities (Fig. 2).

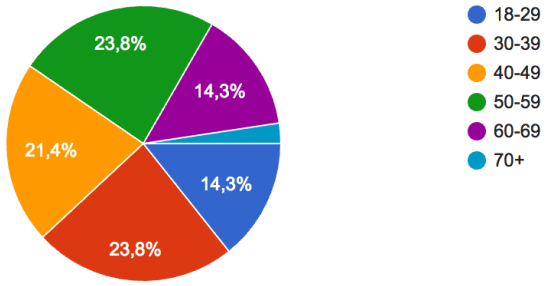

Fig. 1. Sample ages

Regarding how to control the home remotely via an automation system, results revealed that the major interests of totally blind people are related to the handling the lighting system as well as the heating system autonomously living (or being) alone at home, followed by water/gas control valve systems crucial for assuring safety.

Specifically the users declared interest in lighting (81%, 34 users), shutters (36%, 15 participants), thermostat and heating system (95%, 40 participants), conditioning as well as electric network (40%, 17 users), presence sensors/alarm system (36%, 15 users), and valves for water/gas control (64%, 27 users), as shown in Fig. 3.

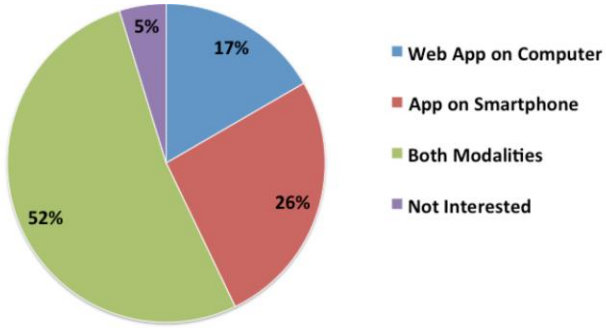

Fig. 2. Preferences regarding interaction devices

Other home devices were selected by a smaller number of users. Preferences and free comments revealed more details and other expectations regarding the use of ICT for home activities performed autonomously and easily. No user reported having an integrated remote control system for home automation, but many people usually rely on electronic tools for support at home. With regard to the existing technical devices and apps available on the market, the survey and interviews collected useful information on their use by the interviewees.

4.1.1 User Usage: Commercial Apps and Tools

More than half of the participants (56%, 23 users) already use some kind of tool to support specific tasks at home. Most tools commonly considered by the blind for home activities are for dealing with lighting and the kitchen. A small number of users (5 totally blind users) had installed a remote control thermostat at home.

Users can take advantage of smart objects such as talking scales for food and people, and personal digital voice labelers for objects, such as PenFriend[3] or Penny Talks.[4] This type of tool is based on special adhesive labels equipped with a unique ID. As a result, the user must buy a certain number of series of numbered labels. Thus, object labelling is limited by the number of labels made available by the supplier and often they are not enough for the user's needs. For this reason, for labelling/recognizing the objects, some people talked about specific apps based on barcode or QR code.[5] In addition, some users interviewed pointed out that the latest version of the operating system (e.g., IOS 11) included the opportunity to read the QR code. But this labeling functionality does not allow the user to add easily customized labels. Therefore, a combination of both procedures might be a valuable solution to reading the code-base descriptions and the customized label added by the user with his/her personal content. We explored this during the meeting; the users reported examples of these cases when identifying products such as medicines or food products; the QR or bar code allows one to read the description, but no indication about the date of expiration is available. Thus, having the opportunity to quickly add new content would be an interesting enhancement. Some users reported performing this task via Braille labels. However, most participants declared that using a smartphone to label and especially to recognize objects is not very comfortable when this activity is performed every day; they prefer a dedicated device, although the possibility of having one usable device for many activities would be interesting. Indeed, opening the app and identifying the label/QR code can require more effort than using a specific device expressly designed for this purpose. The same occurs for other aspects, such as checking the on/off lighting status, and especially for repetitive actions, which must be performed several times a day.

Some users stated they preferred a single device to handle everything, since this does not require learning the features and operating instructions of many different products. They believe that the actual inconvenience is related to the numerous apps developed for performing activities via smartphone; lots of apps means many interfaces and commands to learn, provided the user interfaces have been developed keeping accessibility in mind. Thus, even with a single device problems still exist.

To control lighting, users can use specific tools or mobile Apps, such as Light Detector,[6] which based on the phone camera (pointing at the ceiling for instance) plays a higher or lower sound depending on the light's intensity; this helps the user find the light source and understand whether the lights are switched on. Analogously, Seeing Assistant Home[7] is another application that allows blind users to detect light sources and offers vocal interaction. Three users mentioned a very new app available on the AppStore market called "Seeing AI"[8]. Among other functionalities, it offers a light detector. However, the users declared that the app is too new to be well-evaluated. In the interview session at the local seat of the Association for the Blind, users confirmed there are several apps for light detection all working by the same principle. A number of users reported they

[3] http://www.braillebookstore.com/PenFriend-Audio-Labeler
[4] http://www.talktech.se/en/products/pennytalks-29637026
[5] Digit-eyes, http://www.Digit-Eyes.com
[6] EveryWare Technologies, https://itunes.apple.com/it/app/light-detector/id420929143?mt=8
[7] http://seeingassistant.tt.com.pl/home/
[8] https://itunes.apple.com/it/app/seeing-ai/id999062298?mt=8

have a hardware device specifically developed for light detection such as an audible light sensor[9] or talking color detector.[10]

However, control activity via app or device is not very comfortable. To check whether a light is on or off, the user must move physically to the room (one by one) and remember to bring the smartphone or device in his/her hand. Replicating this check several times, and any time (s)he is about to go out, can require a lot of effort. The users declared that for this activity being able to check the lighting status of all rooms (without needing to move to the rooms) by an app or web-based interface (also remotely) could dramatically improve that task. One user also suggested being able to receive an alert before going out or when changing a scenario (e.g., passing to the night profile) with the lighting status.

In addition, the interviews revealed that a specific device-independent system providing immediate on/off feedback available in each room could be useful for (1) unskilled users or (2) avoiding the need to have the device at hand. For instance, a system associated with each room's lighting that gives out a short sound when switching on and a different sound or silence when switching off, could be also an interesting support to avoid always needing the smartphone or the specific tool in hand any time the light is turned on or off. The interviewed users commented that this modality with the limitation of the recent switches might not offer different positions (on/off) easily recognizable by touch. However, the issue especially occurs in those rooms with the opportunity to turn on/off the lighting from different switches. Thus, such a tool could offer valuable support during daily activities since a beep can be heard any time the lighting is switched on.

Regarding heating systems, participants declared they are usually only able to control the on/off status. To handle and check the temperature/humidity/noise, recently some devices such as NetAtmo[11] have been introduced for remote control via mobile app. Five users reported having a remote tool for heating: three users have the NetAtmo, while two have the Thermo4all, a product specifically designed for visually-impaired people.

However, these devices rely on a Wi-Fi network and for interaction via screen reader an accessible App is needed. This means that an accessible and usable app is necessary for any kind of installed home device. Participants observed that such an approach, although very useful for a blind person, requires many different and distinct Apps requiring effort for the users in learning to use them proficiently. Thus a single remote home automation system controller, integrating all home devices able to deliver all functionalities could be very useful for user empowerment and to increase the personal autonomy of the blind in everyday tasks.

Another kind of solution involves exploiting motion sensors to activate lights or heating systems, which requires modifying the original system, requiring a small investment. However, a totally blind user might not wish to automatically turn on the light when entering a room.

4.1.2 User Expectations

A closed question asked for which of the main remote control systems would they like: heating systems (95%), lights (81%), shutters (36%), air conditioning system as well as electrical system (40%), presence sensors (36%), and water/gas valve control system (64%). The presence sensors were not considered a very interesting device since they are seen as security tools. However, the 36% who declared interest in them thinks those sensors could be useful in many contexts, not only for detecting intruders. For example, a presence sensor allows the user to understand whether a domestic worker is present in the home (at the expected time). Seven participants (17%) mentioned other systems, specifying alarm systems, garden control, water softener, water makers, kitchen appliances, TV/washing machine control, and domestic appliances in general.

More than 78% (33 out of 42) of the participants expressed additional wishes about home remote control and automation systems in the free text field: kitchen appliances, garden devices, mail control, door control, and so on, as reported in Table 1.

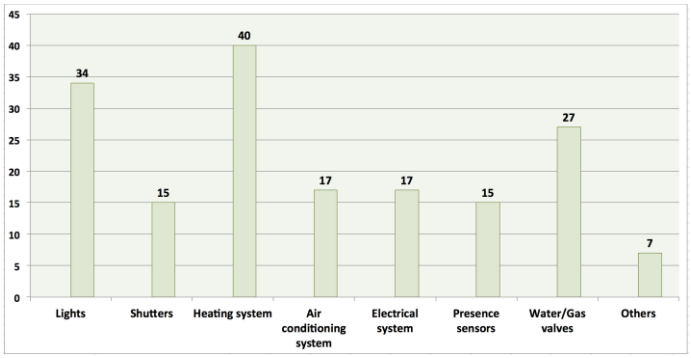

Fig. 3. Automated systems: user preferences

Table 1. Participants' desired functions for home automation systems

Desired functions

• **Alarm system**, anti-theft control (7 users)
  • **Presence sensors.** Knowing whether someone has entered the house (or is still there) (e.g., domestic worker)
• **Outdoor management**: gates, any cameras, etc. Check remotely if someone has rung the bell or left the mail (2 users)
• **Smart garden** (4 users)
• **Simplified integrated appliance control**/ Greater autonomy in the management of home appliances (10 users)
  • For the house I use a Candy washing machine that I can manage via iPhone. My problem is to read clothing labels to get information on how to wash them. I'd like to have an app to read these labels and to speed up the washing machine settings
• **Kitchen support** with greater autonomy in the use of household appliances (12 users)
  • Turn on the oven
  • I would like to have an accessible food processor. I know that many blind people use the 'Bimbi' but it seems to me that the most recent model cannot be managed. It would be nice if there was a vocal control system for managing everything
  • Being able to check what I have in the fridge and the things I still have to buy; understanding which systems are working (washing machine, dishwasher, TV)
• **Smart wardrobe**, Better organization of cabinets/greater autonomy in managing clothes, management of clothes that is not limited to color alone (e.g., matching) (4 users)
• **To label and manage objects**

[9] https://www.visionaustralia.org/information/adaptive-technology/using-technology/day-to-day-items

[10] http://shop.rnib.org.uk/colorino-talking-colour-detector.html

[11] http://www.netatmo.com

4.1.3 User Interface

Answers regarding users' preferences included some useful cues to consider in the user interface design in order to make an integrated remote control system more usable for a blind person. In a previous case study [3] accessibility and usability issues detected while interacting with the Web interface of Fibaro, a popular commercial remote control system, were discussed. Based on these results, a question on the survey investigates usability aspects of device control. Specifically, we asked them to express a preference on how the information could be presented to the user from among the following (single-choice radio button options):

- List of lit lights/open shutters with the ability to turn off/close them (20 users)
- List of rooms in which there is at least one light on/shutter open (16 users)
- List of all lights/shutters with the on/off or open/closed state (6 users).

In addition, 40 out of 42 users agree on the utility of having a button to turn off all the lights or to close all shutters. In fact, this option would simplify the interaction for all, by reducing multiple inspections and actions.

Recently, thanks to smartphone apps, Remote Control Systems enable these kind of actions (directly or via settings), activated with one gesture. This is very useful, but these functions have to be accessible also via assistive technology and specific gestures available on the smartphone when the screen reader is running.

More free comments were expressed by 18 participants, as reported in Table 2. Most requested features are accessibility, usability, personalization and scalability.

Table 2. Participants' suggestions

User Suggestions
• It should be simple, accessible and modular, and customizable according to a person's disability (11 users). • The system should be usable and simplified: a base on which to plug in specific subsystems such as oven, lights, and so on. On this base it would be possible, as needed, to expand the system with specific ad hoc subsystems. • The management system should be unique, standard, with specialized subsystems, expandable according to the needs and to the different abilities of each individual. • The system should be scalable, provided with a base version on which to add new modules. Modules can be aggregated into 3 or 4 sectors (domestic tasks, safety, etc.). I suggest standardizing the usability and scalability of the system. The access should be enabled both via mobile device and PC: locally and remotely. It would not be limited to services available today, but be scalable on personal autonomy services (f.i. smart cabinets, ...) as well as on appliance control. • The button could also be a button for each room, and it must turn off only the lights and not the electrical sockets. • For the lights I would like to be able to turn them off room by room; if I have 3 lights in a room, I would prefer to know that in the room one light is on and be able to turn it off. • I am more concerned with managing domestic things such as cooking or dressing. I use a color device, but quickly recognizing jerseys in drawers is not easy. I know there are systems for labeling objects but I have not tried them. However, I would like to keep a computer archive of things with the description to improve the matching. • You should also be able to manage the alarm system, or know if some device is on. For example, if I left the TV on or if the socket where I connected a charging device is running (so the device is still charging) or the dishwasher has not ended yet. Taking advantage of the presence sensors it would be valuable to see if someone was at home, which does not have to be a thief, but for example the housekeeper who comes to clean.

The possibility of managing personal things and clothes is another important aspect that emerged from this study. Specifically, users expressed an interest in tools to organize and manage their clothes in a more flexible manner: how to organize them, how to match the colors, and so on. A system or app to support the storage and search for clothes and objects could be useful to improve efficiency in managing these items autonomously. Apps like saycolor[12] or cromnia[13] are available but not particularly efficient for this purpose. In addition, reading the labels containing materials, washing features, etc. is not an easy task for a blind person. Thus an app or tool to support this activity has been suggested by some users.

Many users wish to manage the electric household appliances by having a voice synthesizer available on each device. The opportunity to handle the devices via several apps (one for each device) is accompanied by concerns regarding the need to interact with several apps. This can require considerable effort, with a significant cognitive overload. Thus a single system or/and app to manage all the devices and status has been suggested by the most interviewed users.

5. Discussion

The survey clearly revealed an interest in home automation in order to increase personal autonomy of visually impaired people. A curious aspect is that no user reported having a home automation system, while some people had a thermostat or washing machine managed via app. This indicates that the meaning of "automation system" is somewhat unclear; perhaps it is perceived as a very complete and complex system.

The users' expectations with regard to the management of home devices range over various aspects, from using a single application to manage all home services, to solutions that can be combined to offer various accessibility levels as support according to the context of use, available resources and the user's preference or skill.

An unexpected peculiarity that emerged from both the questionnaire and the meeting concerns the opportunity to control and manage lighting, and especially for those who are totally blind. Interest in being able to independently manage the lighting by those who cannot see might seem unusual, but the users pointed out that (1) when living alone the lights might accidentally stay on for a long time, and (2) even when living with sighted people, being autonomous in this task as well can increase one's own inclusion in the family.

Lighting as well as heating system control has highlighted an interesting expectation with regard to the different levels of accessibility support to be guaranteed according to user preferences and skills. Indeed, users have exposed critical issues and concerns about the complexity and reliability of these technologies. Specifically, issues regarding communication with

[12] https://itunes.apple.com/it/app/say-color/id388871655?mt=8
[13] https://itunes.apple.com/it/app/cromnia/id1253491962?mt=8

the devices could create noteworthy difficulties by those who cannot see. Nowadays many devices are only controllable via a mobile app, or via a device panel inaccessible to the visually impaired. This occurs because there is no guarantee of a minimum accessibility level to turn the device on or off via well-perceivable buttons or when no voice support is provided on the home devices. Thus, the ability to manage home devices via a mobile app (with accessible design) offers new opportunities for blind people, but this may not be suitable for everyone because it requires good familiarity with smartphones and with the web interface. Such an approach might not be suitable for elderly and unskilled blind persons. This is the main reason why there is no clear response with regard to the choices between the preferences 'a smartphone application' or 'an ad hoc designated assistive technology'. This is also confirmed by the expectations expressed regarding management of the lighting system; although many commercial (hardware and software) tools are available, the two expectations that emerged are very distant from each other. On one hand, a first support via audio feedback could be supplied whenever the light is turned on by the switch; this solution is in fact suitable for everyone as it does not require any device in hand. On the other hand, a full remote control system is expected to be able to check if all the lights are on, also room by room, with the ability to turn them on/off either one by one or all together.

Briefly, the main users' expectations, concerns and suggestions:

(1) Opportunity for totally blind people to handle the lighting system; an unexpected particular interest was expressed by 81% of the blind users; this was motivated by some difficulties in handling the lighting when living alone or in particular situations.

(2) Chance to manage home devices such as thermostat, washing machines, electric system, and any type of activity that can be controlled remotely. A home automation system allows visually impaired users to perform everyday activities autonomously, which can be impossible or very difficult for them. For instance, checking or setting the heating temperature could not be effectively possible for the visually impaired. Remote control via Web or especially via mobile app can enable a blind person to carry out certain tasks autonomously even when the user is at home. This may be different for a sighted user who can decide to control the home device by the home automation system or not.

(3) Concerns about learning too many functionalities and commands for using remote systems and dedicated assistive technologies. This can occur when too many devices are available for different tasks or especially when the devices have their own Web or mobile application featuring many things to learn and handle.

(4) Concerns about a minimum level of accessibility for the basic functionalities. When a Wi-Fi connection does not work or when users are not familiar with new technology (e.g., smartphone), the blind users expressed concerns about not being able to handle basic functionalities, such as turning the home device on/off.

(5) No clarity of ideas about the preference between a dedicated assistive technology (e.g., hardware light detector) or a single smartphone-based application to handle several activities. Some users preferred a specific assistive technology for carrying out certain tasks (e.g., for object labelling), because those tools are more usable, differently from an app, which requires several steps before being able to perform the needed activity. On the other hand, some users preferred a single device for carrying out a number of activities. A smartphone can handle several apps to control multiple functions. Moreover, assistive tools specifically designed for blind users are often too expensive. For some tasks, a mixed solution has been suggested: for instance, to check whether the lights are on/off a device installed in each room can offer a first feedback level which can be combined with a more sophisticated remote for more careful handling.

(6) Interest in a supported management of other activities at home includes methods and tools for more independence dealing with clothes (arranging, specific apps to check washing instructions, and so on), object recognition and labelling, accessible cooking robots, and voice-based common devices (washing-machine, dishwasher, oven, coffee-machine, etc.).

6. Proposed recommendations

The above results lead us to suggest recommendations for the designers and developers of a remote control system or any application for handling a home device. A summary of these guidelines:

(a) **One interface for all services**: Develop a single application able to interface itself with several apps for remote handling of various services and devices. For example, the app could handle lighting and heating systems, washing machine and dishwasher, and electronic system. This would allow the user to learn and become familiar with only a single interface, provided that it is accessible and especially usable via screen reader and gestures.

(b) **Various services for one device**: Propose more than one solution (when possible) connected reciprocally in order to offer the user various accessibility levels, such as the case suggested by the survey: a specific HW device or sensor installed in any room that provides immediate feedback (a beep) upon switching on the light (no assistive technology or device is needed in hand), and a more structured mobile/web app to specifically handle numerous functionalities and features of the lighting (checking how many lights are turned on, switching off a single light or all of them, and so on). The same should be provided for the heating system, i.e., an app as well as basic accessibility available on the device panel.

(c) **Specific functionalities and customizable scenarios**: Design very specific functionalities and scenarios allowing the user to customize the application as much as possible, tailoring it to their needs. For instance, for the potential scenario "Away from home", the blind user might want to receive an alert like "Three lights are still on; the washing machine is going for 10 more minutes" when he/she is going out or the scenario is activated. Otherwise, a user could prefer to turn off all the lights with ANY message when the "away" scenario is activated. These preferences should be customizable.

(d) **Minimum accessibility level for basic functionalities**: Make accessible at least the key functionalities of a device controllable remotely, even when the wireless connection is down. Modern technology can offer greater opportunities, but when wireless communication is not working a blind user can have great difficulty performing elementary tasks such as switching on/off the thermostat, or starting the washing machine. This can occur when the display is completely touch-based and no speech-support is available or no button is provided for essential commands.

(e) **Accessible and usable interfaces**: Design a user interface that is not only accessible, but especially usable, to arrange functionalities and commands in an effective and efficient

manner. Customization and different devices/status of views seem to be two important features to include in the User Interface design. Specific guidelines for the user interface of a remote control system are needed. The work proposed by [3] highlights some early suggestions in this direction.

These are general suggestions; specific design indications should be provided for the user interface of specific devices and control systems, to guarantee simple use via screen reader as well as via touch interaction. One of the most important concerns expressed by the users concerns the number of commands and their learnability.

7. Conclusions

This paper investigates the habits and expectations of visually impaired people with regard to remote control systems and smart services in order to increase their independence in daily life at home. Difficulties and concerns about popular tools and activities are also reported. Forty-two visually impaired people participated in an online survey and eight of them were then interviewed to obtain better insight into the reported issues and needs. Based on the collected results, we proposed a few basic suggestions for designers and developers.

An accessible smart home is especially valuable for visually impaired people since it can simplify everyday tasks. A remote control system is usually used to allow people to facilitate performing certain tasks or checking device status when away from home (i.e., when the device is not close at hand). Instead, blind people can exploit home automation systems to increase their autonomy at home, being able to handle domestic devices and carry out everyday tasks.

Recent evolutions in technology offer new perspectives through low-cost solutions. It would be very valuable to evaluate using virtual assistants such as Amazon Alexa or Google Home in blind people's homes.

More research is needed to investigate current challenges in simplifying the interaction of people with disabilities with remote control systems, building cheap accessible smart homes, delivering a range of valuable services for special needs users, and offering a seamless integration of smart objects/devices and personal health systems.

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10. Appendix

Following questions composed the questionnaire:

1) Gender

- Female
- Male

2) Age

- 18-29
- 30-39
- 40-49
- 50-59
- 60-69
- 70+

3) Visual impairment: *

- Totally Blind
- Visually Impaired

4) Do you have electronic devices/apps to automate your home (e.g., Light/shutter control systems)?

- Yes
- No

If yes, could you please specify what they are?

(Text box)

5) How do you wish to control/check your home?

- Via smartphone App
- Via PC
- Both
- I'm not interested in automated control

6) Please indicate what you would like to autonomously control in your home (multiple answers):

- Lights
- Shutters
- Heating system
- Air conditioning system
- Electrical system
- Presence sensors
- Water/Gas valves
- Other

7) What other functions do you wish to control through a home automation system? (Text box)

8) Concerning lights/shutters, what do you wish to have?

- List of lit lights/open shutters with the ability to turn off/close them
- List of rooms in which there is at least one light on/shutter open
- List of all lights/shutters with the on/off or open/closed state

9) Would you like to have a button to turn off/on all lights close/open shutters?

- Yes
- No
- I don't know

10) Do you have any suggestions or comments on home automation and remote control systems?

(Text box)