Enabling by Voice

Voice Enabled Environmental Control (EC) Devices Using Interactive Smart Agents (ISA)

Umber Shamim
College of Engineering, Design and Physical Sciences
Brunel University London
Uxbridge, UK
umber.shamim@brunel.ac.uk

Dr Gabriella Spinelli
College of Engineering, Design and Physical Sciences
Brunel University London
Uxbridge, UK
gabriella.spinelli@brunel.ac.uk

Dr Alan Woodcock
North Thames Regional Environmental Control Equipment Service
The Hillingdon Hospital Trust
Uxbridge, UK
alan.woodcock2@nhs.net

Dr Ajoy Nair
Alderbourne Rehabilitation Unit
The Hillingdon Hospital Trust
Uxbridge, UK
ajoy.nair@nhs.net

***Abstract*—Interactive Smart Agents (ISA) like Amazon Echo are rapidly becoming part of our households. These devices are controlled by the user through conversations in natural language. In turn, these agents control other smart devices around the house. Similar control functionalities are provided by Environmental Control (EC) devices issued to people with severe mobility impairments. EC devices are controlled by scan and click methods (also known as switch methods). In case of severe physical impairments such EC control mechanisms become time consuming, frustrating and undignified. These methods rely on the little available mobility of these patients and don't allow them to use the intact cognitive and communication skills they typically retain. This paper argues that an EC device based on voice-controlled ISA could be an option to enable SCI patients to have a better quality of life. However, the current design and development of ISA devices makes them dependent on internet for all the speech processing. Which raises issues related to reliability, security and privacy. ISA devices are designed as mainstream consumer technology. However, the patients' demand for ISA instead of traditional EC devices is growing. However due to the shortfalls, ISA are only prescribed in pilot cases. If the technology and design of ISA were to be addressed, they would represent a significant saving to the National Health Services (NHS). This paper aims to highlight the need for a user-centered investigation on the design of ISA based EC devices.**

Keywords— Interactive Smart Agents; Environmental Control Devices; User-Centered Design; Voice Enabled Technology; User Experience

I. EC Devices

Environmental Control (EC) systems, enable people with severe physical impairment to use a wide range of electrical devices [3]. The first EC system, known as Possum (Patient Operated Selector Mechanism), was manufactured in the 1950s for survivors of the polio myelitis epidemic [4]. With the advancement in technology EC equipment has undergone various changes. The current systems include a control unit, which activates peripheral devices by means of infrared or radio signals [4]. These EC devices can operate through numerous methods for control and input. The most widely used input method is a simple switch-based device. With one click of the switch the user can navigate through different options available for controlling their environment. Other forms of input can include eye tracking, 'suck and puff' and head movement.

EC devices are prescribed by the NHS through regional EC services like the North Thames Regional Environmental Control Equipment Service (NTRECES).

II. User experience with traditional EC devices and Speech-controlled EC devices

The unintuitive and cumbersome part of the user experience when interacting with EC devices is the method used for input, especially for people with severe mobility impairments. [1]. The most popular method of input is scanning-based; this means that the user has to sequentially scan all options available until the required one is highlighted and can finally be selected. Examples of this type of input device are the buddy button (Fig.1.) a single large clickable button, IntegraMouse® (Fig.2.) controlled with the lips, suck and puff whereby one breath counts as one click. In the EC device all the menu options available are displayed in the form of a sequential list. User can browse the menu one by one and choose the options with a single click. Due to the sequential browsing and selection of the options available and when there are several peripherals (TV, lights, curtains etc.) controlled by the EC device, this can become a very lengthy process. Using scanning as an access method caused frustration with technology as it slowed down the speed of use [7]. Moreover, users with deteriorating mobility impairments have growing difficulty in operating the EC [1].

Some other options that are available for operating the EC devices are eye gaze or head mouse. These methods require extensive eye focus and neck movement, which causes tiredness and fatigue, if used for longer periods of time.

Automatic speech recognition is believed to be one of the most promising developments for users who are severely disabled [8]. Research states that users' preferred way to control EC units was to directly interact with them through voice activated commands, rather than select from a menu through a switch-based input [1]. One of the major advantages of speed recognition over other methods of input is its speed efficiency [6]. Speech-driven systems enabled control for patients when other input methods are not possible. It offers a faster and aesthetically considerate option, giving the users a sense of independence and dignity [2].

The ease of use of speech recognition has led to its inclusion into many types of EC integrated systems [8][9][10] one of them is SiCare® Pilot. However, studies highlight that speech-controlled EC devices have reliability issues, which result in patients opting for backup systems for functions such as call for help [2].

Fig. 1. Buddy button

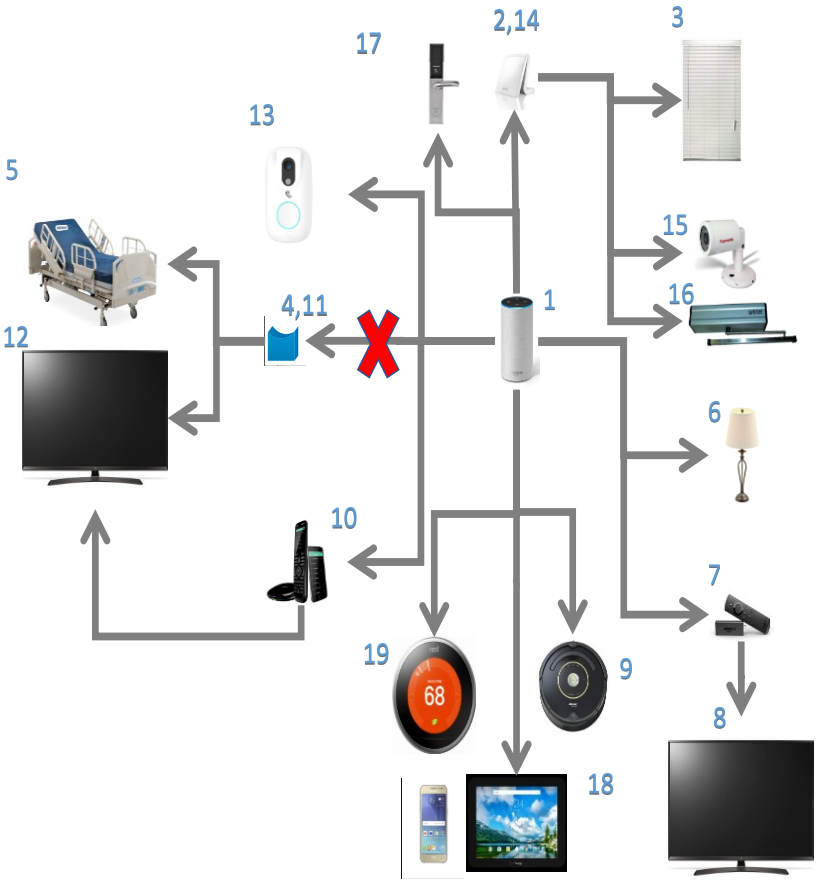
Fig.2. IntegraMouse®

III. ISA DEVICES

ISA devices commonly known as smart speakers, have been on the market since November 2014 when Amazon launched Amazon Echo. They are an evolutionary form of chatBots, which were computer programs, simulating conversations with the user via voice or text [11]. After the release of Amazon Echo, Google has released Google Home, Apple their HomePod and Microsoft came up with Invoke as their versions of ISA devices. The cost of these devices ranges from 299$ for a HomePod, 230$ for an Amazon Echo Show to 29$ for a Google Home Mini. The statistic shows that the market revenue of smart speakers with personal assistants worldwide in 2018 amounted to 11.8 billion U.S. dollars [12]. According to Gartner, the ISA market will reach $2.1 billion by 2020 [11]. Majority of these devices only have audio output, but Amazon Echo Show, Google Home Hub and Amazon Echo Spot, have a display output as well.

The main method of interaction with these devices is through speech. In addition, ISAs can control multiple (IoT) compatible devices for example, smart TV, smart light bulbs, smart doorbells, smart security cameras, automated blinds, smart door locks and openers.

These ISA devices continuously listen to their surroundings using their multiple microphones, on hearing the activation or 'wake-up word', the device starts recording the sound input. This sound clip is then transmitted via the internet to the cloud



No.	Description	No.	Description
1.	Interactive Smart Agent (ISA) Controlled by voice. Settings are modified via smart device.	11.	A bridge device to communicate directly between TV and ISA.
2.	A bridge device to get signals from ISA and send IR signal ahead to different devices	12.	TV, for access to conventional TV channels.
3.	Electric blinds. To be opened and closed by giving voice commands to ISA	13.	Smart front door camera.
4.	A bridge device to communicate between an hospital bed and ISA.	14.	Smart IR Emitting Hub, like Logitech Harmony
5.	An electric bed. To be moved up or down	15.	Conventional CCTV are not compatible with ISA, so can only be controlled with an IR emitting hub.
6.	Lamp. Can be controlled by ISA through smart switch or smart bulbs.	16.	IR Controlled door openers.
7.	Display Control Device for example fire stick.	17.	Smart lock and door openers are directly controlled by ISA.
8.	Monitor. Can be controlled by ISA if a display control device is attached to it through HDMI.	18.	Smart phone will be used to modify settings of ISA. To control the smart phone or tablet or PC by voice windows voice recognition or Android's voice access app will need to be used. No set methods are available to do so through ISA right now.
9.	Robo Smart Vacuum, can be directly controlled by ISA.	19.	Smart thermostats like NEST can be directly controlled by the ISA.
10.	Universal Remote Controls. To control your TV and other electronic devices.		

Fig. 3. Map and list of the functionalities that ISA devices can and cannot provide

servers, where the processing takes place and the ISA device responds to the "user request" accordingly. This request could be either ordering something online, weather information, internet search or controlling of a device connected to the ISA device through the home Wi-Fi.

This continuous listening has raised several security and privacy concerns; users are wondering if all of their conversations are being recorded, for what purpose these recorded sound clips will be used (e.g. targeted marketing etc.). ISA manufacturers have responded by providing several security features e.g. the mute button within the devices. They have assured the users that only the sound clip recorded after the 'wake-up word' will be transmitted to the cloud servers [13].

Moreover, there have been some security concerns regarding the ISA devices. Reliance of these devices on home Wi-Fi and internet makes them vulnerable to malicious attacks. There has been reported incidents where smart devices linked to the internet have been hacked and controlled by outside entities e.g. webcam, baby monitors etc. As smart agents can also be used to control smart locks for home entry, a potential risk is that they could enable unauthorized and malicious entity impersonating the user to obtain illegal access to the user's residence [11].

In addition to that, there are concerns about ISA devices spying on users for market research gains [11]. This effects the trust between the user and the device. However, research found that users mostly trusted the manufacturer companies to protect their privacy [13].

Despite all the security and privacy issues surrounding the ISA devices, numerous studies report a mostly positive user experience. Users personified their ISA devices and treated it as a human because of its ability to hold a conversation. Users reported improvement in their quality of life, not only of the assistance provided by the ISA, but also because of its ability to provide companionship through voice communication interaction [14].

IV. ISA AS EC DEVICE

ISA devices can provide all the functionalities of an EC device, bar a few. This is summarized in Figure 3 above.

A. SWOT Analysis

There are pros and cons for people with severe mobility impairments to use ISA devices as EC device. To compare, different types of devices for example ISA or EC, a SWOT analysis was conducted.

This analysis has been conducted taking into considerations the professional opinions of NTRECES staff and the researcher's experience of the devices under scrutiny.

Table I. SWOT Analysis of EC Devices Controlled by Methods Other than Voice (For Example Switch)

Strengths	**Weaknesses**
1. Reliability 2. Tried and tested 3. Familiarity 4. Compatible with existing (Infra-Red) devices around the house 5. Troubleshooting and backup service available	1. Lengthy selection 2. Un aesthetic designs 3. Lack of input in design from users 4. Gap between current technology available 5. Lack of innovation
Opportunities	**Threats**
1. Adapt the speech recognition technology available 2. Add an emotional human element to the design 3. Introduction of more functionalities	1. New interactive smart agents are offering a more personal experience 2. A software in a smart phone can replace the whole EC device

The major advantage of using a conventional EC device will be its reliability. Whereas, the biggest disadvantage will be the inefficient operation. These devices have been tested through the times but are being threatened by the immense functionalities available in the mainstream off the shelf products.

Table II. SWOT Analysis of EC Devices Controlled by Voice (For Example Pilot)

Strengths	**Weaknesses**
1. Easier and more natural control of devices through use of speech 2. No reliance on internet as all speech processing is done offline. 3. Tried and tested 4. Familiarity 5. Compatible with existing peripherals 6. Troubleshooting and backup service available	1. A device can only learn a limited number of commands 2. Some training time is required initially 3. Less reliable if voice changes in time of distress 4. Failure in case of background noise 5. Alternate control methods are unavailable in case of emergencies
Opportunities	**Threats**
1. Make use of the new technology for natural language processing. 2. Introduction of some interaction abilities in the devices can add a human dimension to the design	1. New interactive smart agents can already understand and respond to commands spoken in natural language 2. With access to the internet, the ISA are a source of infinite information and not just mere home control devices.

One of the biggest plus points of the speech-controlled EC devices is a speedier operation and aesthetically pleasing solution. However, these devices are found lacking in reliability. There is a steep learning curve and only a set number of instructions can be recognized by these devices. The latest speech recognition technology, on the other hand is not bound by such constraints and is very close to holding a conversation in a natural way.

Table III. SWOT Analysis of Interactive Smart Agents (For Example Amazon Echo)

Strengths	**Weaknesses**
1. Ability to respond to Natural Language 2. Ability to hold a simple conversation 3. Control other smart household devices 4. Good sound quality 5. Can be controlled by a smart phone app 6. Can interact with your smart phone or tablet	1. All speech processing is on the cloud so internet availability is a must 2. Less reliable in case of emergency. If the user can't call out or the internet is down 3. Very new technology so early adoption can have its own hiccups 4. No support is available from manufacturers 5. Peripherals that would work with this new technology will be different from the existing ones and will need to be replaced. 6. Will need to comply with standards, to qualify as a medical device.
Opportunities	**Threats**
1. The area of assistive technologies is wide open for these innovative products, with a little or may be no modification these products can be marketed as assistive devices 2. Addition of monitoring functionalities to raise alarms in case of emergencies 3. Provision of offline processing of speech 4. Alternate call for help method 5. Partnering with other manufacturers and assemble an EC package for user with debilitating physical disabilities.	1. Already established assistive devices companies can tap into the agents already available in smart phone and provide the functionality on their own

The biggest plus point in favor of the ISA devices is its ability to hold conversations in a natural way and to be a source of information as well as entertainment. On the other hand, these ISA devices are marketed as main stream devices and do not offer additional qualities that are very critical in Assistive Technology (AT) tools for example reliability.

B. More than an EC Device

People suffering from mobility impairments not only need help in conducting physical tasks, but they need emotional support as well. Often, people suffering from profound disability, end up being home bound. There is a high prevalence of depression and anxiety in people who have compromised mobility [15]. They can lose contact with friends and family and have a non-existent social life. These ISA devices in such cases can offer easier options for communication and keeping in touch with friends and family [16]. Moreover, ISA devices are improving with regards to speech recognition and responding in natural style of conversation as compared to voice-controlled EC devices. This ability of ISA to hold a conversation humanizes the devices in users mind. Some existing users of Amazon echo feel that they share a bond with the smart agent and treat it as a member of the family [17]. In addition to that, due to the ability to connect to the internet, ISA devices can be a source of a wealth of information e.g. weather forecast, traffic reports, to do list, reminders, internet search results. These smart agents not only provide information and automate the home but also provide entertainment and companionship. ISA enable users with mobility or visual impairments to feel more independent, free and safe [18]. Mobility impaired users were able to control smart home appliances like lights, thermostats, door locks, TV etc. independently. Whereas users with visual impairments were able to listen to music or books or news all on their own.

C. Risks of Using an ISA as an EC Device

As mentioned in section III, there are certain issues associated with the usage of ISA devices. One major cause of concern is the dependence of ISA devices on the internet. In addition to that, constant listening to users' conversations for the "wake-up word" is another worry. It gives rise to issues related to reliability, privacy, security and trust.

People with severe mobility impairments are very vulnerable and can be in situations where help is needed urgently. It is of utmost importance that the devices used by them would be always reliable in emergency situations. However, ISA devices fail to function in case of loss of internet or power. There is no in-built battery backup or an option to switch to 4G/3G internet. Hence, people in vulnerable situations should be provided with extra security and privacy options. This downfall also determines that the NHS in the UK does not recognize ISA based devices as assistive technology that can be prescribed.

In addition to that, as already mentioned, after the 'wake-up word' the ISA device records the user's commands and this recording is vulnerable to third party hacking [11]. In April 2019, Amazon Echo announced their health skills, and the

business giant made very clear that they comply to the U.S. Health Insurance Portability and Accountability Act of 1996 (HIPAA) [19]. Amazon is now providing HIPAA eligible environment for developing new health related skills to its business partners. This way it is made sure that all the health sensitive information is properly protected and cannot get into the hands of an unknown 3rd party.

D. User-Centered Investigation on the Design of Voice-Controlled ISA based EC Devices

EC devices have been the subject of several evaluation studies, focusing on quality of life, user satisfaction, user experience, user perceptions, effectiveness, efficacy, benefits and usability ([20], [21], [22], [23], [7], [2], [6], [15], [1], [24], [25]). Overall, users reported frustration with the technology [7]. On the other hand, user's satisfaction was linked to the emotional perception of the devices [26]. It was also noted that, suitability of EC devices to the context and environment of use is one of the major factors in its better utilization. Moreover, the research highlights that clinical personnel prescribing the EC devices could consider the client opinion, efficient set-up and installation, and adequacy of follow-up for the successful ongoing usage of EC devices [21]. Some of the challenges that the medical personnel feel whilst evaluating EC devices include a lack of understanding of the methods that can be employed to conduct evaluations, lack of resources, access to end users and the required expertise to apply evaluation techniques [27].

Following the same trend Regional EC services in England are looking into using standard methods like Therapy Outcome Measures (TOMs) to determine user satisfaction from installation. TOMs [28] is a clinically validated measure that allows professionals to describe relative abilities of clients in four domains: Impairment, Activity, Participation and Well-being. In February 2018, a working group has been established to adapt TOMs specifically for EC services.

Similarly, voice-controlled EC devices were the subject of a qualitative study in 2002-2009 to determine the user perceptions and to inform the design of a new speech or voice driven EC system [2]. Amongst the voice operated EC devices, SiCare Light ® is one of the few that are prescribed by the Regional Environmental Control Equipment Services (RECES) within England [29]. Voice operated EC devices are controlled via a set of pre-defined instructions, differently from ISA-based device that accept natural language instructions. Users go through a period of voice training after installation. This study concluded that there are obvious benefits of speech-driven systems, as it provides an option where other means of input are unavailable given the complex disability of the patients. In addition, voice control devices were found to be more efficient and aesthetically pleasing. Like conventional EC devices speech-driven systems enable a perception of increased independence. However, due to reliability issues the users always preferred a backup or alternative system for certain functions. Unfortunately, the results of this study were only used for academic purposes and were not used to modify the design of speech-driven EC devices.

Using a voice-controlled ISA based EC device is still in its idea phase [30]. The EC services within England are currently exploring the adoption of mainstream devices (for example ISA) as EC devices. This has also been prompted by patients' direct requests for off-the-shelf ISA devices rather than expensive traditional EC. However, as not much time has passed since the introduction of ISAs on the market, there is not much research on their adoption and usage as Assistive Technologies (ATs) [18]. Some companies are experimenting with the use of ISA as EC or AT devices [31]. People with a variety of disabilities, have however taken an independent initiative to use ISA devices as AT tools.

A customized ISA based EC device, designed through the process of user-centered design (UCD), is not yet available. In order to take into account user's experience, needs and demands a UCD approach is critical. Similarly, there is no standardized evaluation criteria for such a device. There is a need to investigate the use of voice-controlled ISA based EC as well as its usability, efficiency and psycho-social impacts. In addition, factors determining the impact of ISA based EC and the differentiating factors amongst conventional EC and ISA based EC require further inquiry and investigation.

V. CONCLUSION

Given the underdeveloped research in this field, there is a need for an exploratory study that will enable to capture rich data not only on the device and its users but also on the context of usage of the ET devices and user experience. Moreover, a qualitative research framework will help in the generation of multi-dimensional data sets which are critical in building a knowledge base [32].

In the proposed study, currently undergoing research ethics approval by the NHS in the UK, patients with severe mobility impairments but good cognition and communication will be recruited through NTRECES, a partner in the collaborative research project. User observations and interviews will be carried out, at the users' place of residence.

There are, however, challenges present in the conducting of this study. Due to the vulnerable condition of the users, utmost caution needs to be taken for their emotional and physical wellbeing. It will not be possible to conduct lengthy observation or interview sessions without any break or without the presence of their carer or chaperon.

The insights from these observation and interview sessions, however, will inform the gaps and opportunities within the design of the conventional EC devices and users' aims and aspirations. In parallel to the study with severely impaired patients, this research will also undertake a user-centred research investigation to understand whether voice in the interaction with ISAs is a factor that contributes to the attribution of agency to these technological devices. This is particularly important because if for fully abled users voice is the preferred means of interaction, impaired users may consequently also prefer this interaction style with their ISAs.

A prototype ISA-based EC device will be designed following the insights generated by the study. These insights and the prototype will aid in the understanding of the user

experience of conventional as well as ISA based EC devices. Further analysis will help to determine, the benefits and concerns of patients and their carers as well as the EC service providers.

REFERENCES

[1] A. Craig, Y. Tran, P. McIsaac, and P. Boord, “The efficacy and benefits of environmental control systems for the severely disabled,” Med. Sci. Monit., vol. 11(1), pp. 32–39, 2005.

[2] S. Judge, Z. Robertson, M. Hawley, and P. Enderby, “Speech-driven environmental control systems a qualitative analysis of users' perceptions,” Disability and Rehabilitation: Assistive Technology, vol. 4(3), pp. 151-157, 2009.

[3] D. Wellings, and J. Unsworth, “Fortnightly review: environmental control systems for people with a disability: an update,” BMJ, 1997.

[4] R. Dicey, and S. Shealey, “Using technology to control the environment,” Journal of Occupational Therapists, vol. 41, pp. 717-721, 1987.

[5] C. E. E. Thornett, “Designing special switches and control systems for multiply handicapped young people, a problem-led approach,” Journal of Medical Engineering and Technology, vol. 14, pp. 87–91, 1990.

[6] M. Hawley, “Speech recognition as an input to electronic assistive technology,” British Journal of Occupational Therapy, vol. 65(1), pp. 15-20, 2002.

[7] M. Verdonck, E. Steggles, M. Nolan, and G. Chard, “Experiences of using an Environmental Control System (ECS) for persons with high cervical spinal cord injury: The interplay between hassle and engagement,” Disability and Rehabilitation: Assistive Technology, vol. 9(1), pp. 70-78, 2014.

[8] J. M. Noyes, R. Haigh, and A. F. Starr, “Automatic speech recognition for disabled people,” Applied Ergonomics, vol. 20, pp. 293–298, 1989.

[9] H. Jiang, Z. Han and P. Scucces, “Voice activated environmental control system for persons with disabilities,” IEEE Proceedings of the 26th Annual Northeast Bioengineering Conference, vol. 62, pp. 167–168, 2000.

[10] F. Aguilera, A. Ataeefar, and R. Brothers, “A personal computer based environmental control system for the disabled,” IEEE Proceedings of the Annual International Conference in Engineering Medical Biological Society, pp. 1533–34, 1992.

[11] H. Chung, M. Iorga, J. Voas, and S. Lee, “Alexa, can I trust you?,” IEEE Computer Society, pp. 100-104, 2017.

[12] Statista, “Smart speaker market revenue worldwide,” https://www.statista.com/statistics/822511/worldwide-smart-speaker-market-revenue/.

[13] J. Lau, B. Zimmerman, and F. Schaub, “Alexa, are you listening?,” Proceedings of the ACM on Human-Computer Interaction, pp. 1-31, 2018.

[14] Y. Gao, Z. Pan, H. Wang, and G. Chen, “Alexa, my love: analyzing reviews of Amazon Echo,” IEEE Smart World, pp. 372-380, 2018.

[15] A. Craig, P. Moses, Y. Tran, P. McIsaac, and L. Kirkup, “The effectiveness of a hands-free environmental control system for the profoundly disabled,” Archives of Physical Medicine and Rehabilitation, vol. 83(10), pp. 1455-1458, 2002.

[16] H. M. Ramsden and J. Samuels, “A review of age friendly virtual assistive technologies and their effect on daily living for carers and dependent adults,” Healthcare, vol. 7(49), 2019.

[17] A. Purington, J. Taft,S. Sannon, N. Bazarova and S. Taylor, "Alexa is my new BFF," Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '17, pp. 2853-2859, New York, New York, USA, ACM Press, 2017.

[18] A. Pradhan, K. Mehta, and L. Findlater, "Accessibility came by accident," Proceedings of the 2018 ACM-CHI Conference, 2018.

[19] R. Jiang, “Introducing new Alexa healthcare skills,” https://developer.amazon.com/blogs/alexa/post/ff33dbc7-6cf5-4db8-b203-99144a251a21/introducing-new-alexa-healthcare-skills.

[20] Å. Brandt, K. Samuelsson, O. Töytäri, and A. Salminen, “Activity and participation, quality of life and user satisfaction outcomes of environmental control systems and smart home technology: A systematic review,” Disability and Rehabilitation: Assistive Technology, vol. 6(3), pp. 189-206, 2011.

[21] M. Myburg, E. Allan, E. Nalder, S. Schuurs, and D. Amsters, “Environmental control systems–the experiences of people with spinal cord injury and the implications for prescribers,” Disability and Rehabilitation: Assistive Technology, vol. 12(2), pp. 128-136, 2017.

[22] P. Rigby, S. Ryan, and K. Campbell, “Electronic aids to daily living and quality of life for persons with tetraplegia,” Disability and Rehabilitation: Assistive Technology, vol. 6(3), pp. 260-267, 2011.

[23] M. Verdonck, G. Chard, and M. Nolan, “Electronic aids to daily living: Be able to do what you want,” Disability and Rehabilitation: Assistive Technology, vol. 6(3), pp. 268-281, 2011.

[24] L. Squires, F. Rush, A. Hopkinson, and M. Val, “The physical and psychological impact of using a computer-based environmental control system: A case study,” Disability and Rehabilitation: Assistive Technology, vol. 8(5), pp. 434-443, 2013.

[25] I. Boman, K. Tham, A. Granqvist, A. Bartfai, and H. Hemmingsson, “Using electronic aids to daily living after acquired brain injury: A study of the learning process and the usability,” Disability and Rehabilitation: Assistive Technology, vol. 2(1), pp. 23-33, 2007.

[26] A. Jardón, Á. Gil, A. De La Peña, C. Monje, and C. Balaguer, “Usability assessment of ASIBOT: A portable robot to aid patients with spinal cord injury,” Disability and Rehabilitation: Assistive Technology, vol. 6(4), pp. 320-330, 2011.

[27] A. Woodcock, S. Fielden, and R. Bartlett, “The user testing toolset: a decision support system to aid the evaluation of assistive technology products,” Work, vol. 41, pp. 1381-1386, 2012.

[28] P. Enderby, A. John, and B. Petheram, “Therapy outcome measures for rehabilitation professionals,” Third Edition, J&R Press Ltd, Guildford, United Kingdom, 2015.

[29] C. Geggie, “Voice control of environmental control systems,” ACNR, vol. 3(4), pp. 22-23, 2003.

[30] K. Noda, “Google Home: smart speaker as environmental control unit,” Disability and Rehabilitation: Assistive Technology, vol. 13(7), pp. 674-675, 2018.

[31] Limited mobility solutions, http://limitedmobility.solutions/index.htm.

[32] A. Blandford, “Semi-structured qualitative studies,” in M. a. Soegaard, The encyclopedia of human-computer interaction, design foundation, 2013.