Evaluating the Usability of an Automated Transport and Retrieval System

Paul Whittington, Huseyin Dogan and Keith Phalp
Faculty of Science and Technology, Bournemouth University, Fern Barrow, Poole, U.K.

Keywords: Assistive Technology, Automated Transport and Retrieval System, Controlled Usability Evaluation, NASA Task Load Index, People with Disability, Pervasive Computing, System Usability Scale, User Interface.

Abstract: The Automated Transport and Retrieval System (ATRS) is a technically advanced system that enables a powered wheelchair (powerchair) to autonomously dock onto a platform lift of a vehicle using an automated tailgate and a motorised driver's seat. The proposed prototype, SmartATRS, is an example of pervasive computing that considerably improves the usability of ATRS. Two contributions have been made to ATRS: an improved System Architecture incorporating a relay board with an embedded web server that interfaces with the smartphone and ATRS, and an evaluation of the usability of SmartATRS using the System Usability Scale (SUS) and NASA Task Load Index (NASA TLX). The contributions address weaknesses in the usability of ATRS where small wireless keyfobs are used to control the lift, tailgate and seat. The proposed SmartATRS contains large informative buttons, increased safety features, a choice of interaction methods and easy configuration. This research is the first stage towards a "SmartPowerchair", where pervasive computing technologies would be integrated into the powerchair to help further improve the lifestyle of disabled users.

1 INTRODUCTION

Smart technology has proliferated over recent years (Suarez-Tangil et al., 2013) due to the popularity of smartphones and other smart devices (e.g. SmartTVs, tablets and wearable devices) that have the potential to improve quality of life, particularly for people with disability.

The Automated Transport and Retrieval System (ATRS) is a technically advanced system developed by Freedom Sciences LLC in the United States of America (USA) featured in New Scientist magazine (Kleiner, 2008). The system uses robotics and Light Detection and Ranging (LiDAR) technology to autonomously dock a powered wheelchair (powerchair) onto a platform lift fitted in the rear of a standard Multi-Purpose Vehicle (MPV) while a disabled driver is seated in the driver's seat. The overall objective of developing ATRS was to create a reliable, robust means for a wheelchair user to autonomously dock a powerchair onto a platform lift without the need of an assistant (Gao et al., 2008).

The rationale behind creating the smartphone system, SmartATRS, was to improve the usability of the ATRS keyfobs shown in Figure 1 (similar to those used to operate automated gates). One of the Authors is a user of ATRS and identified the need to improve the small keyfobs. This was also emphasised at the 2011 Mobility Roadshow in Peterborough (Elap Mobility, 2011). Increased ATRS usability has the potential to attract new users who were originally deterred by the keyfobs.

Figure 1: ATRS Keyfobs.

SmartATRS was implemented as two sub-systems: Vehicle (ATRS) and Home Control, each with a separate Graphical User Interface (GUI). Home Control can operate any device containing a relay, such as automated doors or gates, but is outside the scope of this paper.

SmartATRS is a first step towards a SmartPowerchair, where pervasive computing technologies would be integrated into a standard powerchair.

Whittington P., Dogan H. and Phalp K..
Evaluating the Usability of an Automated Transport and Retrieval System.
DOI: 10.5220/0005205000590066
In *Proceedings of the 5th International Conference on Pervasive and Embedded Computing and Communication Systems* (PECCS-2015), pages 59-66
ISBN: 978-989-758-084-0
Copyright © 2015 SCITEPRESS (Science and Technology Publications, Lda.)

2 STATE OF THE ART

There is an ever-increasing market for assistive technologies (Gallagher et al., 2013), as approximately 500 million people worldwide have a disability that affects their interaction with society and the environment (Cofré et al., 2012). It is therefore important to encourage independent living and improve quality of life for people with disability.

2.1 Automated Transport and Retrieval System (ATRS)

ATRS uses a laser guidance system comprising of a compact LiDAR device coupled with a robotics unit, which is fitted to the powerchair for locating the exact position of the lift and to drive the powerchair onto the lift. Using a joystick attached to the driver's seat, the user manoeuvres the powerchair to the rear of the vehicle until the LiDAR unit is able to see two highly reflective fiducials fitted to the lift. From then on, the docking of the powerchair is completed autonomously. The autonomous control area has an approximate diameter of one metre (see Figure 2).

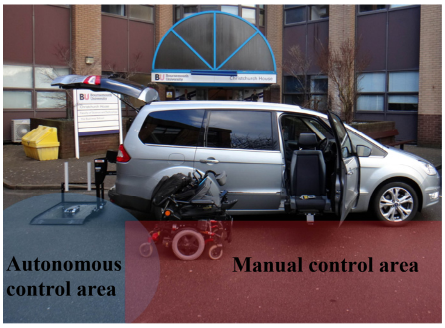

Figure 2: ATRS Operating Zones.

If the powerchair drives outside this area, it will stop instantly and requires manual control via the joystick to return the chair into the autonomous control area.

ATRS requires the vehicle to be installed with three components:

1. A Freedom Seat that rotates and exits the vehicle through the driver's door to enable easy transfer between the powerchair and the driver's seat.
2. A pneumatic ram fitted to the tailgate.
3. A Tracker Lift fitted in the rear boot space.

Although there is an autonomous aspect to ATRS, it is seen as an interactive system that requires user interaction to operate the seat, tailgate and lift. The user group for ATRS consists of people who use powerchairs. SmartATRS was developed to eliminate the small keyfobs that could be dropped easily, falling out of reach.

2.2 User Interaction

A key aspect of user interaction is usability, which is defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (International Organization for Standardization, 1998). The usability of a system has greater importance when the users have disabilities (Adebesin et al., 2010). The success of any system is mainly dependent upon the usability from the "user-perspective" and this can only be achieved by adopting a user-centred design approach early in the design process (Newell and Gregor, 2002). Such an approach was taken when designing SmartATRS, as the requirements of potential users with disabilities were elicited at the 2011 Mobility Roadshow in Peterborough (Elap Mobility, 2011).

SmartATRS has two interaction methods: touch and joystick. In general, each method has limitations, highlighted in research conducted by Song et al. (2007), where a variety of interaction methods for a robot were analysed by performing a user evaluation on five students. It was found that a button interface operated by touch had the slowest mean completion times to move and set the speed of the robot, but was more efficient at controlling rotation. Joystick interaction was identified to be the most efficient overall, as it provided the most consistent performance.

A similar user evaluation was completed for SmartATRS using Controlled Usability Testing (Adebesin et al., 2010). Users performed pre-defined tasks with SmartATRS in a controlled environment to reveal any specific usability problems that could impact the user's ability to operate ATRS safely and efficiently. Usability testing was combined with questionnaires (Adebesin et al., 2010) measuring the extent to which SmartATRS met the users' expectations.

3 THE SMARTATRS PROTOTYPE

Each requirement for the SmartATRS prototype was defined using a shortened version of the Volére Requirements shell (Robertson and Robertson,

SCITEPRESS SCIENCE AND TECHNOLOGY PUBLICATIONS

2009). The requirements were categorized using the Volére types including Safety (SFR), Functionality (FR) and Reliability (RR) and the fit criterion was validated through the usability evaluation presented in Section 4. The key requirements being:

- **(SFR1)** SmartATRS shall not prevent the existing handheld pendants or keyfobs being used as a backup method of controlling ATRS.
- **(FR1)** SmartATRS shall be able to control the following ATRS functions: the Freedom Seat, Tracker Lift and Automated Tailgate.
- **(SFR2)** SmartATRS shall ensure safe operation of all ATRS functions by not creating a risk to the user.
- **(RR1)** SmartATRS shall be reliable, as a user would depend on the system for their independence.

3.1 System Architecture

Figure 3 shows a System Architecture diagram for the prototype SmartATRS. The interactions between the components are shown by the black and yellow lines and the user interactions are shown in red. The diagram contains all of the existing ATRS components and the addition of the hardware for SmartATRS. Wireless keyfobs and handheld pendants were the only method of interaction in the standard ATRS and this presented a limitation in the Human Computer Interaction (HCI). However, SmartATRS allows users to interact by touch or joystick providing a significant improvement in the usability of the system. Junction boxes were manufactured so that the existing handheld pendants remained operational to satisfy Requirement SFR1.

To integrate the System Architecture with the standard ATRS, wiring diagrams were analysed to identify that each component contain relay. A relay board was then used to interface between the ATRS components and the JavaScript. Six relays were utilized for the functions of ATRS: Seat In, Seat Out, Lift In, Lift Out, Tailgate Open and Tailgate Close. The relay board contained an embedded web server storing the HyperText Markup Language (HTML) and JavaScript GUI's as webpages. JavaScript XMLHTTPRequests were transmitted to access an eXtensible Markup Language (XML) file located on the web server that contained the timer durations for each ATRS component. These durations were integers that represented the number of milliseconds each function had to be switched on and were dependent upon the vehicle used (e.g. longer Lift Out durations will be required for vehicles that have greater distances to the ground)

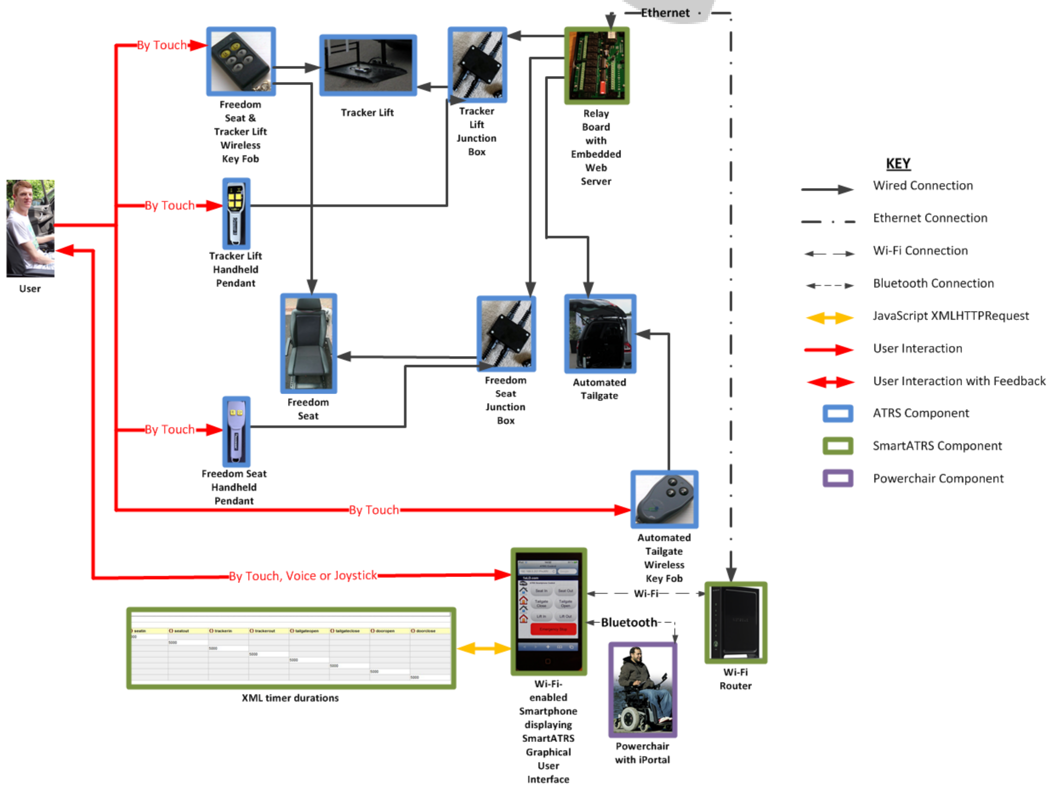

Figure 3: System Architecture Diagram for SmartATRS.

and the preferences of the user (e.g. a greater Seat Out duration maybe required to ensure safe transfers to the powerchair). An XML editor allowed the durations to be easily viewed and changed by an installer via a matrix. The process of editing the XML file was not visible to the end users, thereby ensuring the safety of ATRSy. Ethernet was used to connect the web server to a Wi-Fi router located in the rear of the vehicle, as it has greater reliability than Wi-Fi and this was essential for ensuring the safe operation of SmartATRS. As the relay board is used in an outdoor environment, it could have been exposed to interference from other Wi-Fi networks or devices, which could cause unsafe operation of ATRS. There was no risk of such interference with Ethernet and therefore, Requirement SFR2 was satisfied.

Figure 4: Mounted smartphone and SmartATRS GUI.

A smartphone communicated with the Wi-Fi router over a secure Wi-Fi Protected Access II (WPA2) network and the GUI could be loaded by entering the Uniform Resource Locator (URL) of the webpage or by accessing a bookmark created on the smartphone. Joystick control of SmartATRS was achieved using iPortal developed by Dynamic Controls (Dynamic Controls, 2014) that communicated with a smartphone via Bluetooth and also enabled the device to be securely mounted onto the arm of the powerchair (Figure 4), making the system easier to use.

3.2 User Interface

The rationale for the Graphical User Interface (GUI), shown in Figure 4, was based upon views from the Mobility Roadshow (Elap Mobility, 2011). User feedback and safety features were then incorporated into SmartATRS, which are not present in the keyfobs. Seven command buttons are used to activate each ATRS function. The red Emergency Stop button is twice the width of the other buttons, so that it can be selected quickly in an emergency situation.

Five icons allow the navigation between the ATRS Control GUI and up to four Home Control GUIs. All icons are stored on the web server and can be customized to suit the user's preferences by editing the XML file. An image of a vehicle was used for the ATRS Control icon, whereas the images for the Home Control icons represent the function to be controlled, e.g. a gate or door. The use of large command buttons and clearly defined icons reduces the risk of incorrect selection, ensuring visibility in adverse weather conditions.

The background colour of the command buttons changes to light blue and only reverts to the original colour when the function completes. The exceptions to this are the Tailgate and Lift Out buttons that change to orange and disable when necessary to maintain safe operation of ATRS (Requirement SFR2).

Joystick control was developed as an alternative to touch. In this method, navigation through the GUI is achieved by moving the powerchair joystick left or right and buttons are selected by moving the joystick forwards.

4 EVALUATION

A Controlled Usability Evaluation was conducted on both ATRS and SmartATRS to assess the usability of the interaction methods: keyfobs, touch and joystick. The evaluation provided a means to verify the GUI design ensuring that it was "fit for purpose" for users of ATRS.

4.1 Method

The participants of the evaluation performed six predefined tasks with ATRS:

1. Driving the seat out of the vehicle.
2. Opening the tailgate.
3. Driving the lift out of the vehicle.
4. Performing an emergency stop whilst the seat and lift were simultaneously driving into the vehicle.
5. Closing the tailgate.
6. Driving the seat in and out of the vehicle.

Tasks 1, 2, 3, 5 and 6 were specifically chosen because they must be performed whilst using SmartATRS. Task 4 was included to evaluate safety.

4.2 Participants and Procedure

The evaluation was simulated by forming a user group of 12 participants in powerchairs who could drive a car. Each participant completed an evaluation pack comprising of two questionnaires. The first questionnaire contained ten statements adapted from the System Usability Scale (SUS) (Brook, 1996), where participants' rated ten statements on a 5-point scale from 'Strongly Disagree' to 'Strongly Agree' for keyfobs, SmartATRS by touch and joystick. Example statements included: "I thought using the keyfobs was easy" and "I thought that the emergency stop feature of SmartATRS by touch was safe". SUS was selected as a usability measurement, as each participant was able to provide a single score in relation to each question (Bangor et al., 2008), enabling SUS scores to be calculated for all three interaction methods.

The second questionnaire concerned the workload experienced during the tasks, based on the NASA Task Load Index (NASA TLX) (National Aeronautics and Space Administration, 1996) measuring the Physical, Mental, Temporal, Performance, Effort and Frustration demands. It is a well-established method of analysing a user's workload and is a quick and easy method of estimating workload that can be implemented with a minimal amount of training (Stanton et al., 2005).

4.3 System Usability Scale (SUS) Results

The Adjective Rating Scale (Bangor et al., 2009) was used to interpret the SUS scores, with keyfobs achieving a score of 51.7 (OK Usability), touch achieving 90.4 (Excellent Usability, bordering on Best Imaginable) and joystick achieving 73.3 (Good Usability). This clearly highlights that touch is the most usable; however, joystick can be seen as a significant improvement to keyfobs.

A second important result identified the safety of the emergency stop function. A stopwatch measured the time between the command "Stop Lift!" being exclaimed and the lift actually stopping, revealing a standard deviation of 6.8 seconds for the keyfobs, compared to 1.2 seconds for SmartATRS. The average stopping times were 8.4 seconds and 2.2 seconds respectively. These reductions were due to the participants being required to make a decision to press the appropriate button on the keyfobs, whereas with SmartATRS, the emergency stop button could be pressed to immediately stop all functions.

4.4 NASA TLX Results

The box plot comparisons in Figure 5 and Figure 5 illustrate the differences in the workload experienced when using keyfobs, touch and joystick.

From the minimum, lower quartile, median, upper quartile and maximum values, it is evident that 'touch' showed lower mental and physical demands. Thus proving that keyfobs are more mentally and physically demanding to use than 'touch' and are less efficient.

A second important observation was the higher effort and frustration levels of the joystick in comparison with touch due to it being less intuitive. Another finding was that 'touch' had a greater discrepancy between the maximum values and the majority of the data. The discrepancy was caused by a participant who was not familiar with using a smartphone, therefore making 'touch' more demanding.

There was a minority of users who experienced low workload levels when using the keyfobs, but overall the box plots are fairly conclusive that 'touch' is the most efficient and least demanding interaction method.

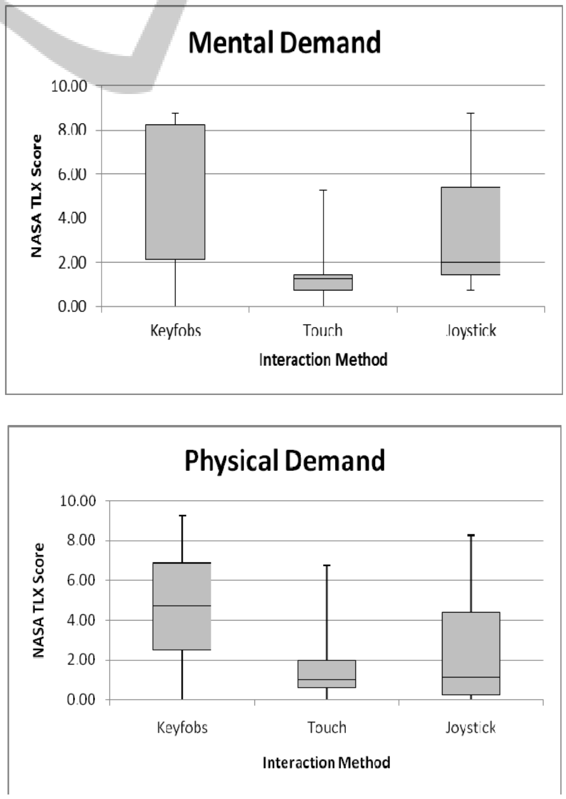

Figure 5: Comparing Mental and Physical Demand experienced.

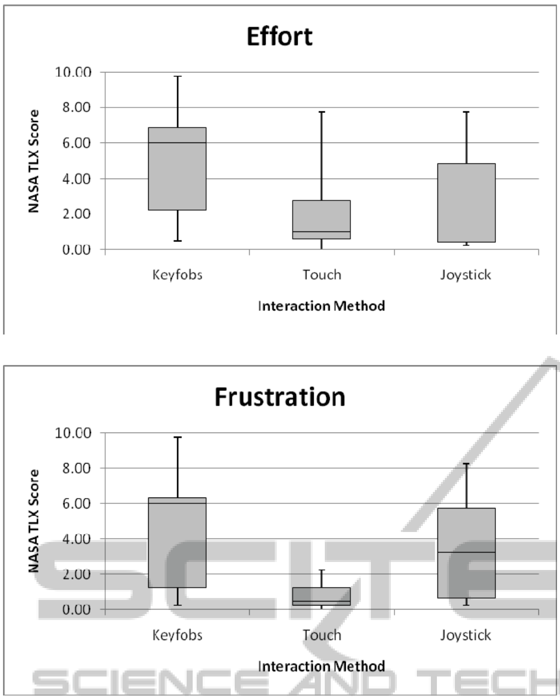

Figure 6: Comparing Effort and Frustration experienced.

5 DISCUSSION

SmartATRS is a new pervasive technology that has been successfully developed to provide an alternative means to interact with ATRS. The key to this was the novel use of a relay board with an embedded web server to interface with the ATRS functions. This created a solution that was smartphone-independent, as the GUI could be accessed with any Wi-Fi enabled smartphone. The use of XML for configuring SmartATRS was efficient as it provided a method that was not visible to the users, ensuring that there was no risk of them tampering with or accidentally altering the timer durations.

Controlled Usability Testing was an effective method of proving that SmartATRS by touch was more usable than the existing keyfobs. Informative statistics were obtained from the questionnaires, which enabled conclusions to be drawn. It was evident that feedback to the user, through the use of button colours and clear text with SmartATRS was a considerable advantage over the keyfobs that provided no user feedback. This was particularly noticeable with the lift where it was difficult to observe the state of the lift from the driver's perspective when using the keyfobs. SmartATRS provides feedback by changing the button colours depending on the current state. The user feedback is particularly important for SmartATRS as it can be viewed as an assistive environment. Metsis et al. (2008) comment, that assistive environments should not be obtrusive. SmartATRS is less obtrusive than standard ATRS as the users are not required to use small keyfobs that need to be carried in addition to a smartphone.

A key finding from the user evaluation was the increased safety of the emergency stop with SmartATRS, where all functions are stopped instantly using a single button press, unlike the keyfobs. The large size of the emergency stop button and its distinctive red colour contributes to safety. This improved safety was reflected by the substantial difference in emergency stop times (6.8 seconds for keyfobs and 1.2 seconds for SmartATRS) and that 100 per cent of participants agreed that the emergency stop with SmartATRS was safe. The importance of robust assistive technologies is acknowledged by Metsis et al. (2008) who recommend that unusual situations must be supported by such technologies to cater for user errors. The NASA TLX results showed noticeable increases in the mental and physical demands experienced when using keyfobs, compared to SmartATRS.

Trewin et al. (2013) conclude that mobile devices have great potential for increasing the independence of people with disability in their daily lives and this is reflected with SmartATRS. The addition of smartphone control to ATRS may increase the independence of users who were initially deterred by the poor usability of the keyfobs.

6 FUTURE WORK

Alternative interaction methods will be assessed and evaluated to determine whether the usability of SmartATRS can be even further improved. The ability to control the powerchair-vehicle interaction using electroencephalograph (EEG), eye and head tracking, as well as voice will be researched. It will be necessary to contact powerchair manufacturers to investigate whether there is an interest in our initiative of integrating pervasive technologies into a powerchair to develop a SmartPowerchair.

7 CONCLUSIONS

ATRS and SmartATRS have been evaluated and

SCITEPRESS SCIENCE AND TECHNOLOGY PUBLICATIONS

shown that an innovative and novel use of pervasive technology has improved usability compared to the small keyfobs. SmartATRS thereby meets a functionality metric defined by Metsis et al. (2008), stating that "an assistive technology must perform correctly in order to serve its purpose".

The user feedback obtained at the Mobility Roadshow highlighted the need to improve the usability of the keyfobs. A SmartATRS prototype was developed that provided a smartphone independent solution that integrated a relay board and embedded web server into the standard ATRS system architecture. The SUS results proved that SmartATRS by touch had 'Excellent' and borderline 'Best Imaginable' usability, compared to the keyfobs that achieved 'OK' usability. Completing NASA TLX on the interaction methods showed that SmartATRS by touch was less mentally and physically demanding than keyfobs. Despite joystick control having higher levels of demand than touch, it was concluded to also be an improved interaction method over keyfobs. Safety of ATRS was enhanced through an emergency stop function that allowed all functions to be immobilised with a single command button, producing dramatically reduced emergency stop times than keyfobs.

The development of SmartATRS has been an initial step to creating a SmartPowerchair. In order to achieve this, future user evaluations will be conducted to identify the most suitable pervasive computing technologies to apply. Through the successful integration of such technologies, a SmartPowerchair is anticipated to further enhance the quality of life and independence of people with disability.

ACKNOWLEDGMENTS

The authors would like to thank the experimentation participants, Keith Whittington and Jane Merrington for their support with the experimentation.

REFERENCES

Adebesin, F., Kotzé, P. and Gelderblom, H, 2010. The Complementary Role of Two Evaluation Methods in the Usability and Accessibility Evaluation of a Non-Standard System. *In: The 2010 Annual Research Conference of the South African Institute for Computer Scientists and Information Technologists: proceedings of the 2010 Annual Research Conference of the South African Institute of Computer Scientists and Information Technologists* Bela-Bela, South Africa, October 11-13, 2010. New York, NY: ACM Press. 1-11.

Bangor, A., Kortum, P.T. and Miller, J.T, 2008. An Empirical Evaluation of the System Usability Scale. *International Journal of Human–Computer Interaction*, 24 (6), 574-594.

Bangor, A., Kortum, P.T., Miller, J.T, 2009. Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale. *Journal of Usability Studies*, 4 (3), 114-123.

Brook, J, 1996. SUS: a "quick and dirty" usability scale. *In:* Jordan, P.W., Thomas, B., Weerdmeester, B.A. and McClelland, I.L., eds. 1996. *Usability Evaluation In Industry*. London: Taylor and Francis, 189-194.

Cofré, J.P., Rusu, C., Mercado, I., Inostroza, R. and Jiménez, C, 2012. Developing a Touchscreen-based Domotic Tool for Users with Motor Disabilities. *In: 2012 Ninth International Conference on Information Technology: New Generations: proceedings of the 2012 Ninth International Conference on Information Technology: New Generations* Las Vegas, NV, April 16-18, 2012. Piscataway, NJ: IEEE.

Dynamic Controls, 2014. *iPortalTM Dashboard* [online]. Christchurch, New Zealand: Dynamic Controls. Available from: http://www.dynamiccontrols.com/iportal/ [Accessed 10 December 2014].

Elap Mobility, 2011. *A Successful Mobility Roadshow 2011* [online]. Accrington: Elap Mobility. Available from: http://www.elap.co.uk/news/a-successful-mobility-roadshow-2011/ [Accessed 10 December 2014].

Gallagher, B. and Petrie, H, 2013. Initial Results from a Critical Review of Research for Older and Disabled People. *In: The 15th ACM SIGACCESS International Conference on Computers and Accessibility: proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility* Bellevue, Washington, WA, USA, October 21-23, 2013, New York, NY: ACM Press. 53.

Gao, A., Miller, T., Spletzer, J.R., Hoffman, I. and Panzarella, T, 2008. Autonomous docking of a smart wheelchair for the Automated Transport and Retrieval System (ATRS). *Journal of Field Robotics*, 25 (4-5), 203-222.

ISO 9241-11, 1998. *Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs) - Part 11: Guidance on Usability*. Geneva: International Organization for Standardization. ISO 9241-11.

Kleiner, K, 2008. Robotic wheelchair docks like a spaceship. *New Scientist* [online], 30 April 2008. Available from: http://www.newscientist.com/article/dn13805-robotic-wheelchair-docks-like-a-spaceship.html [Accessed 10 December 2014].

Metsis, V., Zhengyi, L., Lei, Y. and Makedon, F, 2008. Towards an Evaluation Framework for Assistive Technology Environments. *In: The 1st International Conference on PErvasive Technologies Related to Assistive Environments: proceedings of the 1st international conference on PErvasive Technologies*

Related to Assistive Environments Athens, July 15-19, 2008. New York, NY: ACM Press. 12.

National Aeronautics and Space Administration. 1996. *Nasa Task Load Index (TLX) v. 1.0 Manual*. Washington, WA: National Aeronautics and Space Administration.

Newell, A.F. and Gregor, P, 2002. Design for older and disabled people – where do we go from here? *Universal Access in the Information Society*, 2 (1), 3-7.

Robertson, J. and Robertson, S, 2009. *Atomic Requirements: where the rubber hits the road* [online]. Available from: http://www.volere.co.uk/pdf%20files/06%20Atomic%20Requirements.pdf [Accessed 10 December 2014].

Song, T.H., Park, J.H., Chung, S.M., Hong, S.H., Kwon, K.H, Lee, S. and Jeon, J.W, 2007. A Study on Usability of Human-Robot Interaction Using a Mobile Computer and a Human Interface Device. *In: The 9th International Conference on Human Computer Interaction with Mobile Devices and Services: proceedings of the 9th international conference on Human computer interaction with mobile devices and services* Singapore, Malaysia, September 11-14, 2007. New York, NY: ACM Press. 462-466.

Stanton, N. A., Salmon, P. M., Walker, G. H., Baber, C. and Jenkins, D. P, 2005. The National Aeronautics and Space Administration Task Load Index (NASA TLX). *In:* Stanton, N. A., Salmon, P. M., Walker, G. H., Baber, C. and Jenkins, D. P., eds. 2013. *Human Factors Methods: A Practical Guide for Engineering and Design*. Farnham: Ashgate Publishing.

Suarez-Tangil, G., Tapiador, J., Peris-Lopez, P., Ribagorda, A, 2013. Evolution, Detection and Analysis of Malware for Smart Devices. *Communications Surveys & Tutorials*, 99, 1-27.

Trewin, S., Swart, C. and Pettick, D, 2013. Physical Accessibility of Touchscreen Smartphones. *In: The 15th ACM SIGACCESS International Conference on Computers and Accessibility: proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility* Bellevue, Washington, WA, USA, October 21-23, 2013, New York, NY: ACM Press. 19.

SCITEPRESS SCIENCE AND TECHNOLOGY PUBLICATIONS