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WISH

[Wheelchair Integrated System for the Home]

Abstract—**"When physical disability prevents convenient independent living the first option usually considered is to try and adapt the home"[1]. This is an important step to help wheelchair users live independently. However, due to the widespread uptake of technology, a home automation solution has become a viable alternative to such adaptations. This project aims to improve the quality of life of wheelchair users by exploring the idea of automating and centralizing the user's home experience. Whether the user wishes to turn off the lights or turn on the fan, they can control any device through a wireless system from their wheelchair thus reducing the need for difficult physical exertion or costly remodelling of the home.**

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I. Introduction

Simple tasks such as switching the lights off in a room may seem like an easy task for some, however for wheelchair users they can be laborious challenges. Many locations are now required to be adapted for people with physical disabilities. For example, disabled toilets are commonplace in retail outlets and employers are legally required to make 'reasonable adjustments' to the workplace to accommodate disabled employees' needs.(2)

However, the domestic setting, where the typical wheelchair user will spend most of their time, is often the least adapted to the needs of the disabled resident. The vast majority of homes are simply not designed with the needs of disabled users in mind.

The traditional solution is to modify the home with adjustments such as lowering light switches and moving sockets to more accessible locations. This work is often costly, inconvenient for the resident and may reduce the resale value of the home significantly.

Our solution is to design a system that uses a combination of modern technologies in order to improve the quality of life of the wheelchair bound user, without the need for remodelling of the home.

The system would allow wheelchair users to control crucial elements, such as lighting and appliances in their home with ease.

For this project to be feasible, the method by which the user interacts with the system has to be intuitive and accessible to even the least technically skilled user. The system also needs to be cheaper or comparable in cost to the traditional alternative. It will naturally also provide an additional level of convenience.

With features such as lighting control, appliance control and voice recognition, Wheelchair Integrated Systems for the Home (WISH) would assist wheelchair users in independent living.

II. Overview

The original plan was to design an electric wheelchair with an integrated home control system. This would have to include a human-computer interface, a computer system and a rechargeable power supply as part of the wheelchair.

The problem with this concept is that the bulk and weight of the system would be very inconvenient. Also, this would require the user to have an electric wheelchair. This would put it out of the price range of many users, and others may simply prefer to have a manual wheelchair that doesn't need to be recharged.

An alternative solution is to use a mobile application, communicating wirelessly with a stationary central control server which then sends commands to the units to be controlled via X10, an industry standard home automation protocol.

Compared to the mounted interface, a mobile application would be much more cost-effective, less cumbersome and easier to implement. There is also no need to custom build, or even modify, the wheelchair itself. A disadvantage of the mobile application is that the server must be turned on for WISH to function; however, as explained in Section II, our stationary server is extremely low power.

For our project, the mobile application and control server solution was the clear choice, so this is what we proceeded to research.

Figure 1 presents the overall concept of the WISH system. Sections III to VIII will go through this concept, explaining each stage of the process presented below.

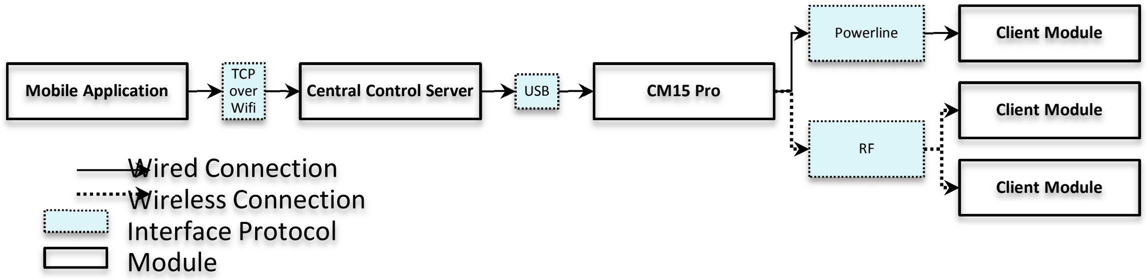

Figure 1 - A diagram showing the flow of commands through WISH.

III. Mobile Platform and Application Development

Platform Choice

In order for us to be able to tailor our home automation solutions to the needs and preferences of individual users, we decided it would be best to use a commercially available device running the Android operating system, and author a mobile application, rather than come up with our own fully bespoke solution which would be costly and inflexible.

Android is a Linux based operating system designed primarily for mobile devices. Android is free and open source, released under the Apache 2.0 Software Licence[3]. This means that the software is permitted for modification, distribution and use for commercial purposes[4], such as WISH.

The devices that Android runs on are inexpensive and readily available. There are a range of devices, from small smartphones to large tablets. We would be able to choose a device to best suit the user, depending on their needs, and their particular disability. Smart phone type devices, which the user may already own, are perhaps more appropriate for people whom are physically impaired but still have some independent mobility, and the tablet type devices would be suitable for mounting on clients' wheelchairs. However, this choice would be at the client's discretion.

Programming the Application

Android applications are developed in Java, a high level, object oriented language. The main purpose of the application would be to take input from the user interface and send the corresponding commands to the server, via the TCP protocol over the user's Wi-Fi connection (see Figure 1).

The Android operating system provides integrated Wi-Fi connection capability and Java provides two APIs (Application Programming Intefaces) for TCP communication, *Socket* and *ServerSocket*, contained within the *java.net* package[5]. Since the mobile application would only act as the TCP client, we would be concerned only with the *Socket* class. Naturally, Android also provides an extensive API for Graphical User Interface (GUI) design and implementation. These are the three key operating components of the application, and they are certainly possible on the Android platform.

Application Design

Of course, aside from the technical challenges of creating the app, we need to design the interface in such a way that it is easy to use for any of our clients, no matter what their disability. This will include a number of different modes, which will be pre-set by us but can be changed easily by the user:

- 'Big Button' Mode. GUI elements increase in size in order to be easily read by users who have impaired vision.
- Haptic Feedback Mode. A small vibration is emitted by the device upon each GUI interaction, somewhat emulating the feeling of pressing a physical button rather than touching a screen.
- Narration Mode. Using the built in Text To Speech API[6] we can read aloud GUI elements to readers who have severely impaired vision.
- Voice Control Mode. For users who prefer or need to control WISH using their voice.

We have created the following mock-ups of what the application might look like, as shown in figure 2. We will make the applications as easy to use as possible, both in terms of intuitive layout and easy to read and interpret. We are confident that a design such as this is very possible on the Android platform.

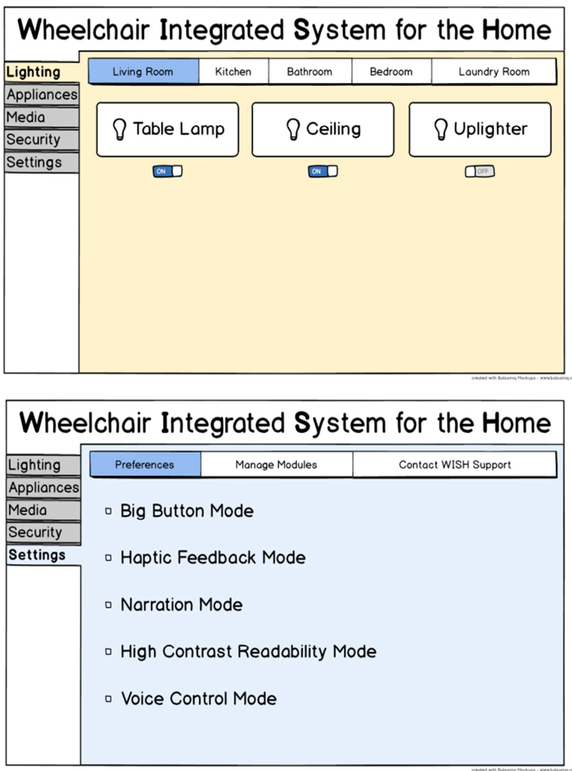

Figure 2 – Proposed app interface/Top: Lighting. Bottom: Settings.

IV. Control Server

At the heart of WISH is a control server that interfaces with the mobile application and the various client modules throughout the home. Figure 1 shows the flow of information from the user to the device.

The server will be a computer running a distribution of the Linux operating system, since it is free and has wide support for the interfaces we need to operate. The criteria for this unit are small physical size, low power consumption, Ethernet connectivity and USB capability. An ideal candidate would be an inexpensive ARM based computer like the Raspberry Pi Model B, due to its low power consumption (3.5W)[(7)], network connectivity, and low cost of USD35. A low power and low cost x86 implementation may also be viable, but we would struggle to match the low power and cost of the Raspberry Pi.

The computer will be running server software, which will be written by us. The server's task is to open a Transmission Control Protocol (TCP) port on the Local Area Network (LAN) and listen for commands from the Mobile Application, which will be connected to the LAN over Wi-Fi. These commands will be in a format that is similar to X10, but the X10 specification does not include command transmission over TCP so the commands will not actually be X10 commands. An example of these commands is given in figure 3.

The server then interprets these commands and then sends the relevant instructions to the CM15Pro Interface, connected through USB, which then relays these commands to the relevant modules via Radio Frequency (RF) or through Powerline Communication (PLC), which refers to transmission over the AC wiring already installed in the user's house.

The software to perform these functions can be written in many different languages; the only requisites being that it must be compliable on the architecture of choice, have a TCP library available and preferably an SDK (Software Development Kit) for interfacing with the CM15. These requirements still include most of the major languages, i.e. C/C++, Java, and Python. High efficiency execution isn't a high priority, since X10 is an inherently slow protocol anyway, therefore we are able to choose a less efficient but easier to write language such as Python.

0001	0110	1010
4-bit House Code	4-bit Unit Code	4-bit Command

Figure 3 - A diagram showing the format of the 12 bit commands issued by the Mobile Application

V. Home Automation Methods

The X10 protocol is the industry standard for home automation. Developed in 1976 by Pico Electronics Ltd, the X10 protocol is one of the first protocols to ever be standardised.[(8)] As such, it is the most compatible protocol and is very popular.[(9)]

X10 and its major competitors Universal Powerline Bus and INSTEON all use PLC. The beauty of this is that the digital command data is sent across the domestic power circuit, without any need for costly modification, and the signals are small enough in amplitude to have no effect on any appliances other than those connected to modules.

The main issue with using PLC is that mains wiring in a home is inherently noisy and some domestic appliances use Switch Mode Power Supplies, which introduce even more noise into the system. This noise has the potential to interfere with the PLC system.

An alternative to PLC is using wirelessly transmitted protocols such as Zigbee and Z-Wave. These offer faster and more reliable communication, while X10 is inherently slow with a maximum speed of 50 bits per second[(10)]. Though faster wireless protocols are faster than PLC, we decided that their additional cost is not worth the speed benefit they provide, especially since home automation does not require particularly fast reaction.

After the decision to use PLC, we simply had to decide on a specific protocol. X10 is particularly cheap relative to its alternatives [(11)] and has the advantage of being the most popular and widely supported home automation protocol. For these reasons we chose to use X10 for the project.

VI. Technical Explanation of X10

The X10 implementation of PLC essentially operates by sending high frequency packets of data over a household's 240V AC power line from a command module. The packets of data consist of an address and a command, encoded within a 120kHz carrier [12]. The amplitude of this signal is high enough so as to negate the effects of noise, yet low enough so as not to interfere with normal operation of standard appliances. These data packets are then demodulated and interpreted by the destination module, which then performs the desired operation.

At each zero crossing of the AC sinusoid 1 bit of data is transmitted through the mains circuit. A binary 1 is represented by a 1ms burst of the 120kHz signal, starting within 200µs of the zero crossing, and a binary 0 is represented by the absence of such a signal.

Each X10 signal begins with the ‘start’ code 0b1110, so that the modules around the home know that a command is coming. The next four bits represent a house code A-P, and the following four bits represent either a unit code or a command. This 12 bit sequence is known as an X10 ‘frame’. Each frame is repeated twice in succession in order to check for corruption. Each frame must be immediately followed by six ‘0’ bits to reset the hardware listener, so that it is ready to listen for the start code of the next frame.

The frame specifying the target unit must be followed by a frame specifying the command to be executed.

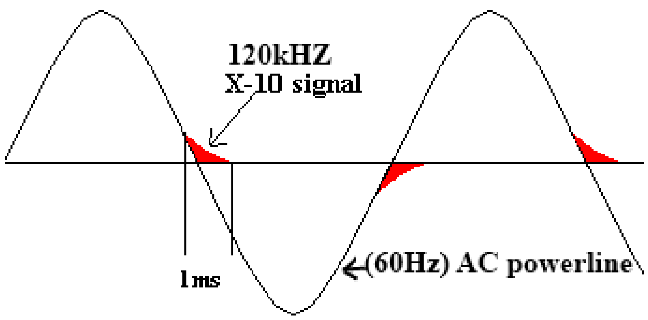

Figure 4 - X10 data packet transmission over AC line

Different modules and thus appliances can be distinguished by the 8-bit module code assigned to each device; this offers control of 256 devices.[11]

VII. Computer Interface

The computer interface is an essential part of the WISH system. It allows our Control Server to interface with the power line network, and make use of the X10 protocol.
There are many computer interfaces we could use. The FireCracker CM17a[13] is reasonably priced and provides sufficient functionality for use in our system, however it uses the RS-232 Serial interface. These ports have become obselete and have been replaced on almost all modern machines by USB ports. Therefore, a device with a USB interface, such as the CM15Pro from Marmitek, would be more appropriate.
The module simply plugs into our server at one end, and into a standard three pin domestic socket in order to communicate over PLC.
Another feature of the CM15Pro is that it allows for communication with other X10 transceivers via RF.

VIII. Lighting and Appliances

To control ceiling lights, the lighting circuit in each room will have a Marmitek LWM1P module wired into the circuit. This can be done behind the light switch or in the ceiling rose.[14]

The reasons for choosing the LWM1P are[15]:

- The size of the module allows it to be fitted behind the switch and in ceiling rose.
- It is a 2-way module which means it can send its status back to the controller, e.g. to confirm the command was successfully received or to inform the controller of the degree of which it is currently dimmed.
- It has ON, OFF and DIM functionality.

A drawback with the LWM1P is that the ability for 2-way communication requires a neutral connection[15], which is not common in standard light switches[14], so connection within the light switch would be preferable. A cheaper alternative to the LWM1P (£80.50)[16] is the Marmitek AWM2P(£70.45)[17]; the AWM2P does not offer a dim function however.

With regards to connection of appliances there are many different appliance modules available to cover a range of different needs. This means the appliance modules used will vary depending on the appliance to be controlled and needs/desires of the user. WISH will be tailored to the user’s requirements.

For example, to control a table lamp you could use one of:[18,19]

- Marmitek AW12- ON/OFF, low power consumption, small, £35
- MarmitekAMM31- ON/OFF, 50 times the power of the AW12, medium size, £29
- Marmitek LW12- ON/OFF/DIM, low power, small, £32

This is not an exhaustive list. There are many possible factors involved in choosing the appropriate module: such as price, power, size and functionality. In each installation case we would choose modules to best suit the client's requirements.

IX. Security and Safety

The primary function of WISH is to provide convenient control of lighting and appliances for the disabled user. However, we are interested in the idea of expanding the system to integrate control over the house's security system and add some safety features for the user, which are very helpful if the user lives alone. We have done some preliminary research based on these ideas.

Surveillance cameras that operate over Internet Protocol (IP) could be installed on the exterior of the abode. The video feed would be available over the LAN and viewable via the WISH app. Giving the user the power to view the exterior of their home at the touch of a button would be a very desirable feature for the system.

There are a few ranges of door locks available on the market[20] which are compatible with the X10 protocol. This would mean that the wheelchair users would have a full mobile control of every entrance to the house, which combines with the surveillance cameras to create a very convenient system to allow external access to the home.

If the user desires an intercom style system, a speaker and microphone could be mounted near the primary entrance, allowing communication between the user and visitors outside the house. The user would speak on the phone and the app would relay their speech to the visitor outside, and vice versa.

For extra security, we can use the built in GPS functionality of the tablet or smartphone to report the user's location to the central server at home every 30 seconds, and the house will activate its safety system and not respond to any command. This is to prevent anyone from breaking into the house either by force or by breaching the wireless system's security.

X. Installation, Testing and Maintenance

In order to install WISH into customers' homes we would have to assess each home differently and tailor the system accordingly. One of our team members would make a visit to the customer's home and consult with the customer with regard to what appliances they want to control. We would then research the options for modules, estimate installation time and quote the customer accordingly.

After installing the system we would test each module to ensure that it works correctly. We would also test the system with all appliances in the house (such as televisions) turned on, to establish whether PLC will still operate. This is because some household appliance power supplies inject noise into the mains and others act as low pass filters, effectively attenuating the X10 signal. In these cases, extra filters will have to be added to the system.

Another potential problem that we could encounter when installing the system into large homes is signal attenuation. As they travel through the long lengths of electrical cabling in the house, the X10 signals become weaker, rendering them unreadable at the destination. In these cases, the WISH system would utilise the RF functionality of the CM15Pro. This would allow us to connect additional transceiver (such as the Marmitek TM13[15]) modules into the system. These extra modules communicate with the primary module over RF, which is more reliable within a home, and then send the relevant commands using PLC. An alternative is to use repeaters, which boost the signal over long lengths of mains cable, however they can also 'repeat' the noise, worsening the problem.[21]

In terms of aftercare and maintenance, we would offer free repairs for any problems with WISH for the first year after installation. Cover for additional years can be purchased, or we can repair the system for a one-off cost.

Of course, due to the open nature of the WISH system, we would make provision for a user with enough technical proficiency to remove modules from their system and purchase and install new modules.

We would also ensure that appliances can still be controlled manually in case of any fault in WISH.

XI. Cost Benefit Analysis

A cost benefit analysis was performed with the ultimate aim of commercial feasibility in mind.

Our analysis was carried out using the assumption of an average, one-bedroom household designed for a wheelchair user, an example is given in figure 5. In addition to a small 9’x16’ bedroom, we assumed other factors such as a kitchen, bathroom, living room and laundry room were also included in our estimation of the average household cost.

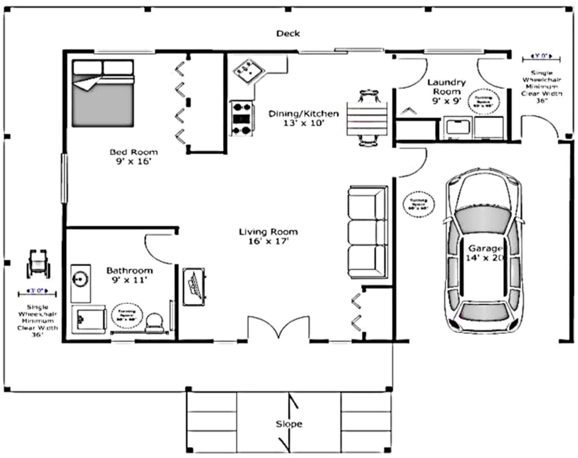

Figure 5[22] – One bedroom wheelchair access floor plan

We based our analysis on the following rooms and appliances, representing the average household:

Bedroom	• Ceiling Light • Table Light • Curtains • 1x General Appliance
Living Room	• Table Lamp • Ceiling Light • Uplighter • Curtains • 1x General Appliance
Kitchen	• Ceiling Light • 1x General Appliance
Bathroom	• Ceiling Light
Laundry Room	• Ceiling Light

Based on these assumptions we can make the following assumption on hardware costs. These figures were sourced directly from a major X10 hardware supplier (Marmitek), based at industry cost price (i.e. no markup). In this model we include the LM15EB Bayonet Lamp Module, LM15ES Screw Lamp Module and the AM12U Appliance Module.

Room	Hardware	Cost (£)	Qty
Bedroom	• LM15EB • LM15ES • AM12U	• 21.60 • 21.60 • 22.30	• 1 • 1 • 2
Living Room	• LM15EB • LM15ES • AM12U	• 21.60 • 21.60 • 22.30	• 1 • 2 • 2
Kitchen	• LM15EB • AM12U	• 21.60 • 22.30	• 1 • 1
Bathroom	• LM15EB	• 21.60	• 1
Laundry Room	• LM15EB	• 21.60	• 1
Other	• CM15Pro	• 42.30	• 1
	Total (£)	326.60	

Although we will offer free consultation we envisage additional labour costs in a commercial setting with regards to installation on a home-by-home basis. Thus we estimate the total costs of installing the WISH system to be as follows:

Stage	Cost (£)
X10 Hardware	326.60
Installation	400
Total	726.60

The social benefits of such a WISH are numerous. WISH hopes to reinstall a sense of independence amongst wheelchair users. However, one of the challenges of a cost-benefit analysis is to equate a quantifiable cost to all benefits and cost. For this analysis, we chose to represent the benefits of WISH as the savings to a consumer on hiring a personal care assistant or similar. Thus assuming a minimum wage of £6.19/hour[23], we assume the following savings:

Hourly Savings	£6.19
Daily Savings (8 hour Working Day)	£49.52
Yearly Savings (253 Working Days)	£12,528.56

However, these savings are based on a best-case scenario for the benefits of the WISH system. It should be noted that WISH may not be a complete substitute for a carer in every case.

XII. Project Management

Project management was approached with the concept of 'division of labour' specifically in mind. The project as a whole was analysed in terms of project goals and aims, and then divided into a logical series of individual tasks. These tasks were then specially allocated to team members based on areas of interests, suitability and previous experience. This allowed each sub-group to focus on researching their own respective areas, the results of which would be then reported back to the group and collated through weekly meetings. The proposed project tasks are as follows:

- Appliance automation
- Lighting automation
- Mobile app development
- Security

By allowing members to specialise on their respective areas of study, we hope to achieve increased productivity and more efficient time management.

XIII. Conclusion

We began this project with the aim of creating a product that could improve the quality of life of the 750,000 wheelchair users in the UK alone[24]. We specifically identified the challenges that an unadapted domestic setting presents to a wheelchair bound person. Features of the home such as lighting, security and appliance operation can present a major challenge to a person of limited mobility.

To come up with a bespoke solution of our own we set out to combine existing technologies into an integrated system to benefit wheelchair users in their own homes, without the need for costly modifications to the building itself.

The solution that we found was to use a smartphone or tablet running the Android operating system to run an application designed by us which would take user input. The application could then issue commands, via the TCP protocol, over the user's existing Wi-Fi connection to our custom designed control server. This server would then pass these commands to a module which would communicate, via the well-established X10 home automation protocol, with the individual lights, appliances and security systems within the home.
Through this system users would have a convenient and reliable way to control their home without having to struggle against their disabilities. Through this report we have discussed the technical challenges and feasibility of designing and installing such a system. From our findings, we believe that such a system can provide an easy-to-use and cost effective way to improve the lives of wheelchair users.

As technology progresses, systems such as this will become more prolific. As costs reduce, these systems could become common place in the homes of wheelchair users, improving the quality of life of each user. However, we also foresee widespread use by people without disabilities who wish to take advantage of the convenience provided by the integrated home automation system.

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