# A Development Model of an Embedded System for Improving the Mobility of People with Physical Disabilities

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**Abstract.** Worldwide there is a high amount of people with disabilities. For instance, according to the National Council for the Equalization of People with Disabilities, there are approximately 418,001 people with disabilities in Ecuador. On the other hand, nowadays there are a lot of electronic devices that allow people to perform everyday activities in a fast and easy way. Considering these premises, the automated control of electronic devices through mobile devices has emerged as a new challenge, whose main goal is to improve the quality of life of people. In this work, we present HomeR, a system that allows people, including people with disabilities, to manage smart home appliances through a mobile application. This system uses the Arduino and Raspberry Pi technologies to provide a low-cost solution that can be used by people independently of their status and abilities. HomeR was evaluated in terms of its implementation cost and accessibility. The results show that HomeR can be implemented in real environments with a low investment compared to already available solutions in Ecuador.

**Keywords:** Arduino · Raspberry Pi · Home automation · Paraplegia

## 1 Introduction

Nowadays, there are a lot of electronic devices that allow people to perform everyday activities in a fast and easy way, thus improving the quality of life of users. Due to this phenomenon, automated control of electronic devices through mobile devices has emerged as a new challenge in which Human Computer Interaction (HCI) plays an important role [1]. For instance, in [2], authors present an ontology-based natural language interface that allows users to interact with different home appliances through instant messaging services.

On the other hand, paraplegia refers to impairment or loss of motor and/or sensory function related to the thoracic, lumbar, or sacral spinal cord segments [3]. People with


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paraplegia are unable to walk hence they must use wheelchair or assistance devices for mobility. Therefore, there is a need for automation and control processes focused on providing safety for people with paraplegia. In this sense, there are several works that aim to solve mobility problems of paraplegic people. Even Artificial Intelligence has been used for this purpose [4].

According to the National Council for the Equalization of People with Disabilities [5], there are approximately 418,001 disable people in Ecuador, of which 196,758 people have a physical disability. Regarding this group, 148,487 people do not have a job and lack economic income. With this regard, Government grants them a monthly monetary bonus, as well as specialized medical assistance through the Ministry of Social Inclusion.

According to the Ecuadorian Institute of Statistics and Censuses, 9 out of each 10 Ecuadorians have a cell phone, of which 53.9% are smartphones. Also, 36% of the households have access to the Internet. Hence, it is necessary to take advantage of these devices, to develop a system that can be embedded in them to improve the life quality of people with paraplegia.

In this work, we present a system that aims to improve the life quality of people with disabilities, including paraplegia. This system uses already available technology, and it is supported by embedded systems [6], which are composed of hardware and control software. Furthermore, it aims to provide a low-cost solution since not all people have the economic resources to implement this system in their home or office.

In order to carry out this work, people with paraplegia who attend the Ecuadorian Society Pro-Rehabilitation of Crippled [7] were asked to collect information about relevant and important activities that they perform within their home or environment. Some of these activities are: controlling ventilation, lighting control, wheelchair movement, and controlling the room temperature. Based on such information, we established their automation needs.

The technological solution suggested allows people with paraplegia to perform all activities above mentioned. This application was developed by using smart home automation devices. A prototype of this system was installed considering the performance of the intelligent home network model [8].

The rest of this work is structured as follows. Section 2 describes a set of related works. Section 3 describes the architecture of the proposed solution. Section 4 analyses the results obtained from a survey performed to Ecuadorians from different social status. Finally, conclusions and future work are presented.

## 2 Related Works

In the literature, there are different works that aim to provide solutions for people with paraplegia. For instance, UbiTrak [9] is a location application that combines indoor and outdoor information. This application has proven to be accurate, and feasible to be used in real-world scenarios.

In [10], a home automation system is presented. This system allows controlling different home appliances, thus contributing to the safety of elderly people or people with disabilities [11].

Some of the current solutions integrate technologies such as Cloud computing. For example, in [12] authors evaluate the use of a Cloud-based robotics system to provide assistance services for the promotion of the active and healthy ageing. Despite the fact that the system obtained good results, authors suggest deeper investigation about the reliability of the communication technologies adopted by this system.

On the other hand, in [13] authors present a low-cost system that allows remotely controlling and monitoring home appliances and several sensors in the home by means of an Android application.

In the last years, several approaches based on WiFi connectivity have been proposed [14–17]. Although this kind of solutions has been applied at a commercial level, their implementation requires great investment.

It is important to design computer models based on embedded systems that allow communication between users and machines. In this sense, the present work takes as reference the work presented in [18], at the same time that most current solutions use embedded systems to integrate hardware and software focused on the users' needs [19].

The research efforts presented in this section are clear examples of the successful use of embedded systems for implementing home automation systems that benefit people from different domains e.g. older adults and people with disabilities. Hence, it is important to contribute to the improvement of this kind of technology to generate low-cost solutions.

## 3 Design and Implementation

This section describes the design and implementation details about HomeR, an embedded system that allows people to manage smart home appliances through a mobile application. HomeR represents a low-cost solution thanks to which several housework activities that require much time and effort were automated.

### 3.1 HomeR Architecture

A sensor network consists of a set of intelligent sensors that are connected among them through wire or wireless mechanisms. In the context of networks, each network component that has a module is known as node [20].

HomeR architecture is composed of two main elements, namely: a hardware-software component and a user interface. HomeR uses the Arduino platform as it offers a high compatibility with several sensors and it is easy-to-use technology regarding its development environment, programming languages, and the Arduino boards. Furthermore, this technology is multiplatform, i.e., it can work on different operating systems such as Linux, Windows, MacOS, among others.

The HomeR architecture takes as reference the work presented in [21], which aims to provide a system that uses low-cost hardware to obtain data in real time, as well as to show this data to the users. Next section describes the main components that have been used as the basis for the development of the prototype.

- **Arduino Uno.** This component [22] consists of an MCU (Micro Controller Unit) based on RISC (Reduced Instruction Set Computer) which works at a clock speed of up to 8/16 MHz. This hardware has a flash memory module of 32 kB (0.5 kB are used by the boot loader) and a SRAM (Static Random-Access Memory) module of 2 kB. Furthermore, this board has 11 digital pins that can be configured as input or output. These pins have been used for the HomeR implementation since it is through them that the Internet connection is established. Another important feature of the Arduino platform is the Bootloader that runs on the microcontroller. This component can be reprogrammed through an USB converter, which makes it easy the configuration of the sensors used in the project. Finally, it should be mentioned that in the Arduino platform [23] all computing and communication processes (except Ethernet) are handled by the microcontroller. This fact allows the project to be extended in future work.
- **Raspberry Pi3 with SD camera and charger (raspberry pi kit).** Raspberry Pi [24] solves the problem of remote communications [25] that is present in Arduino, thus allowing to take advantage of all features of an open connectivity. In this work, Raspberry [26] works as a Web Server [27] that helps monitoring all sensors and collects data from them. This information is stored in a small database.
- **Gas sensor.** The gas sensor [28] ensures a safety level within home. When it detects a high level of gas, it sends an alert to the user. Therefore, it is important for this element to have high sensitivity and fast response time.
- **Relay.** It is managed by the Arduino electronic board and allows turning on/off the lights.
- **Servo motor.** (Metal Servo Motor) It is a small motor that can move in different directions and angles [29] without losing stability. This element helps moving the wheelchair from the mobile application [30].
- **Cables (jumper male to male, female to female).**
- **Others.** Also, this project uses an ethernet cable, a USB camera, LEDs and a power supply.

The HomeR's architecture is presented in Fig. 1.

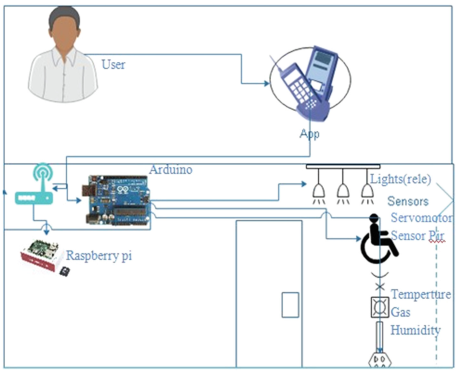



**Fig. 1.** HomeR architecture.

The HomeR's architecture was implemented through a set of iterations, where each of them involved analysis, design and implementation tasks. The result of the first iteration was a basic architecture which was incrementally refined. In a nutshell, the HomeR work as follows: the user interacts with the lights, wheelchair and other sensors through a mobile application. This application receives all data collected by the Arduino microcontroller and the Raspberry Pi card.

## 3.2 Methodology

The methodology used for the development of HomeR involved to carry out a survey on a sample of 120 people with paraplegia from the SERLI (Ecuadorian Pro-Rehabilitation of Crippled) [7]. This survey aimed to know the people requirements according to their daily activities and the demographic and socioeconomic characteristics of all of them.

The survey results are shown in Table 1, where it can be noted that 98% of people think that a mobile application for people with paraplegia is needed. Furthermore, the intended use of this kind of application is of 82%.

**Table 1.** Variables analyzed in a survey to patients with paraplegia.

| Variable | Frequency | % |
|---|---|---|
| Cell phone | 120 | 100% |
| Cell phone usage frequency | 88 | 73% |
| Apps usage | 90 | 75% |
| Need for Apps for people with paraplegia | 117 | 98% |
| Intended use of Apps for people with paraplegia | 98 | 82% |
| Average | 102.6 | 86% |

Also, people involved were asked to sort a set of activities according to the importance they have in their daily life. The results obtained are shown in Table 2.

**Table 2.** Importance of the activities considered by the App.

| Activity to perform through the App | Importance (Avg.) |
|---|---|
| Turn-on and Turn-off home appliances | 8 |
| Ventilation | 7 |
| Lights | 6 |
| Wheelchair movement | 5 |
| Gas system | 4 |
| Open and close doors | 3 |
| Open and close windows | 2 |
| Security regarding fire or intrusion | 1 |

In Table 2, it can be noted that most people see security regarding fire or intrusion as the most important fact to be considered by the application. Meanwhile, the turning on/off home appliances is the least important task.

Also, the survey provided relevant information related to the number of people that are benefited from a human development bonus. Based on all the information obtained from the survey, the requirements and the budget were established.

The system here presented was developed by using the Android operating system, particularly the Ice Cream Sandwich version. Also, Putty was used as an SSH client (Secure SHeel) to manage the Raspberry card from the mobile application. The Python language was used since it provides a graphical user interface to access and controlling several home appliances.

Figure 2 depicts the main functionalities of the system, which are: (a) turning on/off the lights, (b) ventilation, (c) gas sensors, (d) humidity of the environment. It should be mentioned that the system provides a remote connection between the smartphone and the sensors distributed in the house. Also, it allows obtaining the location of the user.


**Fig. 2.** Sensors distribution within the house.

Figure 3 presents the general model of the remote monitoring process, where it can be noted that the system allows users to manage all components at home by using the mobile application. For this purpose, users need to log into the system. Then, the system shows them all available devices that they can manage.

Figure 4 presents a set of interfaces of the mobile application: (a) it allows users to log into the system, (b) it provides a perspective of all devices that users can manage, (c) it shows data collected by the sensors such as temperature, humidity, and gas, and

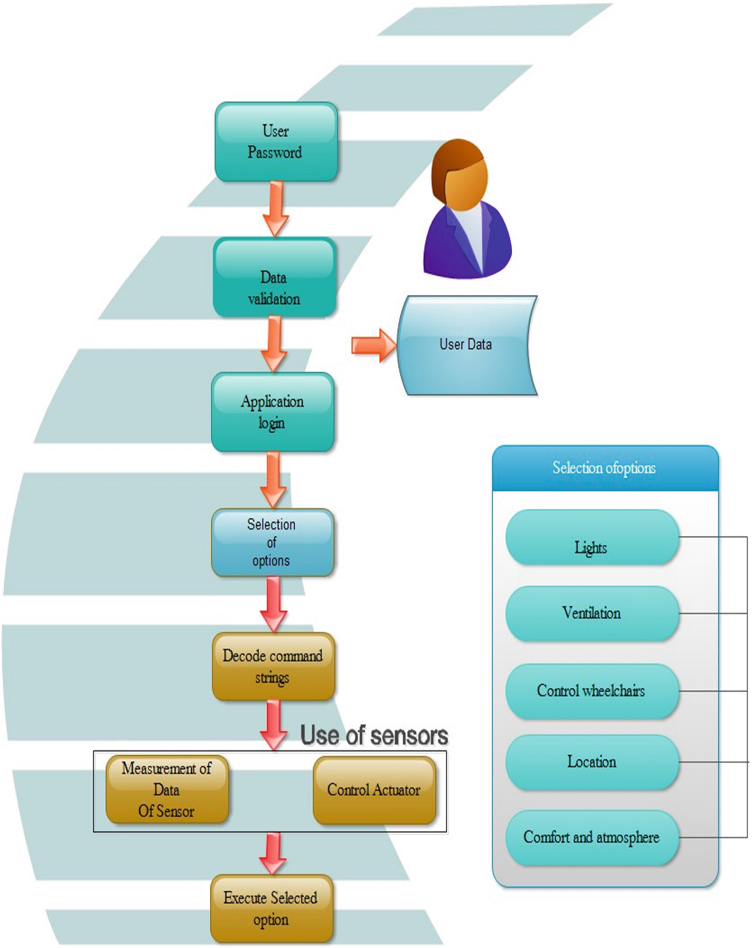
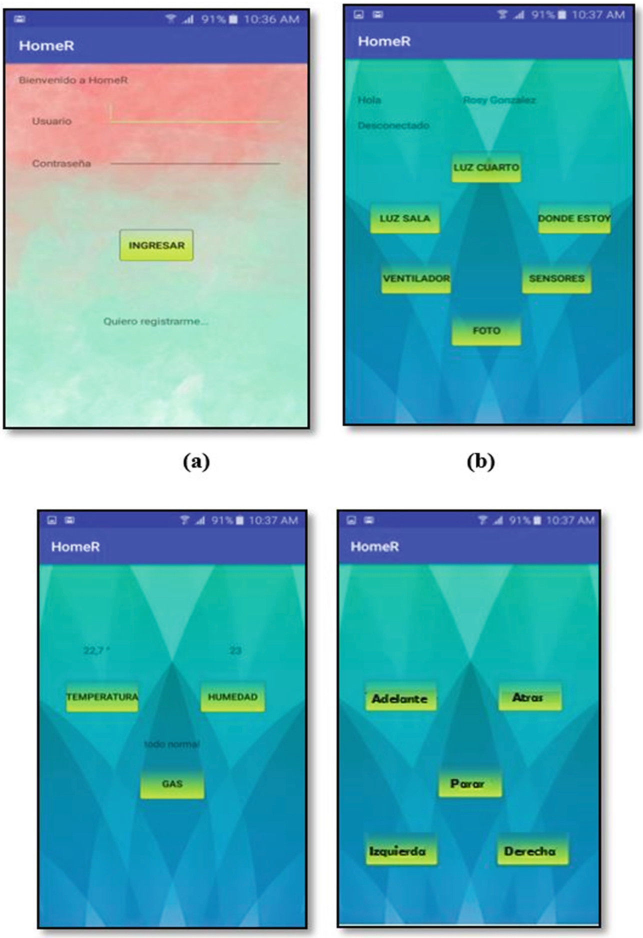



**Fig. 3.** Remote monitoring process.

(d) it allows users to move the wheelchair in four directions (forward, backwards, left and right) as well as to stop moving.

The system can activate an alarm when a gas leakage is detected as well as when the humidity of the environment is high. To ensure its correct performance, the sensors must be correctly installed. When the temperature is too high or low, users can control the ventilation. Regarding the GPS location [31], it is stored in a text file which is sent via email. In this sense, it is worth mentioning that the GPS location is estimated by using the Wi-Fi signal.




(a) (b)

(c) (d)

**Fig. 4.** User interfaces of HomeR.

# 4 Results

To know the people's point of view and their expectations about HomeR, the system was evaluated inside SERLI facilities. For this purpose, the people sample population that was involved in the requirements specification were asked to collaborate again. This validation consisted of two phases which are described below.

In phase 1, people were asked to install the mobile application and to analyze all functionalities provided. Then they were asked to answer a survey about complexity of installation, implementation, aesthetic, download time and intuitiveness. Table 3 presents the evaluation results of the first phase. According to these results, 76.7% of patients consider that the installation process was very easy, and the aesthetic of the

**Table 3.** Evaluation results of the HomeR system (Phase 1).

| Variable | None | Low | Medium | High | Higher |
|---|---|---|---|---|---|
| Complexity of installation | 0.8% | 3.3% | 19.2% | 34.2% | 42.5% |
| Implementation | 0.8% | 3.3% | 16.7% | 33.3% | 45.8% |
| Aesthetic | 2.5% | 4.2% | 9.2% | 37.5% | 46.7% |
| Download time | 0.8% | 3.3% | 15.0% | 31.7% | 49.2% |
| Intuitiveness | 0.8% | 3.3% | 15.8% | 30.0% | 50.0% |
| Average | 1.2% | 3.5% | 15.2% | 0.8% | 46.8% |

application was very pleasant. Also, most patients (80%) consider that the application is very intuitive.

Phase 2 had three main goals: (1) to analyze the patients' point of view regarding the usability, functionality, reliability and accessibility of the embedded system, (2) to know the opinion about comfort and compatibility of the hardware, and (3) to analyze the time they spend to perform the activities through the application. Regarding the third goal, the time spent with the application was compared to the time they spend performing the tasks without the application. Table 4 presents the results related to the first goal. Based on these results, it can be concluded that most patients feel comfortable about using the application.

**Table 4.** Evaluation results of the HomeR software (Phase 2).

| Variable | None | Low | Medium | High | Higher |
|---|---|---|---|---|---|
| Usability | 0.0% | 0.8% | 20.8% | 36.7% | 41.7% |
| Functionality | 0.0% | 1.7% | 15.0% | 37.5% | 45.8% |
| Reliability | 0.0% | 0.8% | 12.5% | 31.7% | 55.0% |
| Accessibility | 0.0% | 0.8% | 8.3% | 33.3% | 57.5% |
| Average | 0.0% | 1.0% | 14.2% | 34.8% | 50.0% |

Table 5 presents the results related to the second goal of phase 2. It must be noted that 98.3% of patients think that HomeR allows controlling home devices in an easy and intuitive way. Furthermore, the compatibility of the system with several sensors was successful.

Another aspect that was considered by this evaluation is the implementation cost regarding hardware. Table 6 shows a comparative among the average cost of hardware used in HomeR and the real cost of it. As it can be noted from Table 6, there is a big difference between the costs, which amounts to $ 585.79.

**Table 5.** Evaluation results of the HomeR hardware (Phase 2).

| Variable | Yes | No |
|---|---|---|
| Comfort | 99.2% | 0.8% |
| Compatibility | 97.5% | 2.5% |
| Average | 98.3% | 1.7% |

**Table 6.** Hardware costs of HomeR in phase 2.

| Functionalities | Average cost | Implementation cost | Difference | % |
|---|---|---|---|---|
| Location | $ 56.23 | $ 27.00 | $ −29.23 | 51.98% |
| Turn on/off lights | $ 105.85 | $ 23.96 | $ −81.89 | 77.36% |
| Ventilation | $ 41.22 | $ 25.68 | $ −15.54 | 37.70% |
| Wheelchair movement | $ 581.96 | $ 241.89 | $ −340.07 | 58.44% |
| Gas sensor | $ 91.58 | $ 15.00 | $ −76.85 | 83.67% |
| Humidity of the environment | $ 56.21 | $ 14.0 | $ −42.21 | 75.09% |
| Total | $ 933.32 | $ 347.53 | $ −585.79 | 62.76% |

Finally, the time patients spend performing the activities by means of HomeR was compared to the time they spend performing the tasks without this application. As can be noted from Table 7, there is a big difference between these values.

**Table 7.** Usage time of HomeR.

| Functionalities | With HomeR | Without HomeR | Difference | % |
|---|---|---|---|---|
| Location | 3 | 1.26 | −1.74 | 58.00% |
| Turn on/off lights | 5.2 | 1.15 | −4.05 | 77.88% |
| Ventilation | 5.4 | 1.2 | −4.2 | 77.78% |
| Wheelchair movement | 10.5 | 4.3 | −6.2 | 59.05% |
| Gas sensor | 14.8 | 2.1 | −12.7 | 85.81% |
| Humidity of the environment | 15.6 | 2.3 | −13.3 | 85.26% |
| Average | 9.08 | 2.052 | −7.032 | 77.41% |

Usually, people with disabilities need help to perform their daily life activities. Therefore, based on the results obtained, HomeR is an application that must be considered by patients with paraplegia because it helps them to carry out this kind of activities in an autonomous way. Furthermore, HomeR have proven to be effective regarding detection of gas leaks, which makes the system reliable in terms of security.

## 5 Conclusions and Future Work

This work presents HomeR, a system that aims to improve the life quality of people with physical disabilities including people with paraplegia. This solution is based on free hardware and software. HomeR was evaluated in terms of its implementation cost and accessibility. The results show that HomeR can be implemented in real environments with low investment compared to already available solutions in Ecuador.

As future work, authors plan to implement a larger scale project that allows implementing home automation of at least 50% of people with paraplegia who receive the human development bonus in the city of Guayaquil. This project aims to have high social impact by establishing links between people and advanced technologies. In this sense, the graphical user interface of HomeR must include new mechanisms that improve the human-computer interaction. For this purpose, we plan to integrate natural language mechanisms that allow people to interact with their home devices in an easier and more intuitive way, regardless their status and abilities.

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