Home Automation System for People with Visual and Motor Disabilities in Colombia

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Keywords: Home Automation, Visual Disabilities, Motor Disabilities, Wi-Fi, Arduino.

Abstract: In this paper we present the development of a home automation system based on a Smartphone with touch to speech feedback. The purpose was to solving problems of accessibility and comfort inside homes for people with visual disabilities. The technological design was based on the development of a web server using an Arduino Uno and a Wi-Fi Shield. The router connects the smartphone to the web server. Then a router connects a smartphone to the server to receive information about the home location and send control signals for power up the household appliances. The tests were performed on people with visual disabilities and people with motor disabilities.

1 INTRODUCTION

People with disabilities presents many problems of inclusion in our country Colombia. For example, those who have visual impairments have difficulties of orientation and mobility inside buildings (Lancioni et al., 2010), (Mirza et al., 2012). This situation may be eventually affecting the daily activities of these persons inside homes and buildings: opening doors, answering the telephone and power up the household appliances (Aburukba et al., 2016), (Mirza et al., 2012). In this way it is necessary the intervention and help of caregivers affecting the independence of this people.

In recent years a series of automated devices and systems have been developed with the purpose of solving this problem avoiding the need of caregivers (Ahmed et al., 2016), (Mirza et al., 2012). These devices made part of a system called Domotic. These are responsible for controlling the operation of devices in a home, in order to reduce human intervention (Faroom et al., 2018).

One of these previous works provides help to people for the remote control of household appliances through a power interface arranged inside a box that has several power AC sockets (Aburukba et al., 2016). In this case the patient activates the devices through a software and an entry button. The system is controlled by an Arduino powered by relays and Bluetooth transmission. The use of these technology is an advantage due to its fast deployment and low costs.

The Domestic Area Networks (HAN) have also been used to facilitate the supervision and control of electronic devices remotely (Aburukba et al., 2016). They are implemented through a system with XBEE wireless modules (based on IEEE 802.15.4) connected to a Wireless Sensor Network (WSN) with the purpose of obtaining a scalable and low-cost topology.

In South America devices have also been developed with the aim of providing health services and increasing the level of independence of the mentioned population (Freitas et al., 2015). The solutions developed are based on the use of technologies with low complexity and price. These solutions frequently use a small single-board computer like Raspberry Pi, motion sensor and wireless network (Wi-Fi) to configure and monitoring settings through a smartphone. In this way we facilitate interaction with the system when moving inside the home.

Systems have also been developed based on the recognition of hand gestures and voice commands with the purpose of providing self-dependence and comfort (Iqbal et al., 2016). This kind of solutions consists of a Kinect module, a control PC and X10 modules to control the appliances wirelessly.

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Coral, W., Alarcon, A., Llanos, J. and Hernandez, J.
Home Automation System for People with Visual and Motor Disabilities in Colombia.
DOI: 10.5220/0007929303330340
In *Proceedings of the 16th International Conference on Informatics in Control, Automation and Robotics (ICINCO 2019)*, pages 333-340
ISBN: 978-989-758-380-3

In this paper we present a Domotic system controlled by mobile devices developed in Colombia. The purpose is solving comfort, accessibility and indoor location problems of people with visual and motor disabilities inside a building.

This work will be presented as follows, in section II System Overview, we give a general view of the system. Then in section III Hardware, we present the infrastructure of the prototype that are complemented with the system description in the section IV Software. Ends with the experiments and results in the section Results and the conclusion.

2 RELATED WORK

Smart Home Automation (SMA) systems combine electronics, communications and data processing devices and end-user applications for household appliance management and indoor location systems. Currently these systems are based on wireless communication standards for the establishment of a common network of home devices (Konings et al., 2016).

The SMA can also integrate internal positioning systems (IPS) that use radio frequency signals, magnetic fields and acoustic signals. These signals are collected by a mobile device with the purpose of getting people location (Els et al., 2016). A special application is the use of these systems for solving the problems of interior location for people with disabilities (Mirza et al., 2012).

2.1 Technologies used in IPS

One of the most common indoor positioning techniques is Radio Frequency Identification (RFID) technology (Li et al., 2015), (De Cillis et al., 2017). This is due to its low cost of installation and maintenance because most of the RFID systems do not require cabling infrastructure. However, radio frequency signals from RFID systems could easily be blocked by external devices tuned to the same frequency. On the other hand, for indoor location purposes a smart phone could not be used as a location device and an additional RFID card would be required. In this way if we want to use the smart phone to help people with visually impaired it would be necessary to use additional routing and conversion devices to send RFID over the wireless Ethernet standard IEEE 802.11 (Wi-Fi).

ZigBee technology operating under the IEEE 802.15.4 standard is also used for IPS applications due to its cost efficiency, low power consumption, low processing capacity and transmission speed of 250Kbps (Konings et al., 2016), (Bianchi et al., 2018). However, for RFID it would not be possible to use smart phones as devices for the interior location of people with visual disabilities, because these devices could not connect to the ZigBee network.

Through Wi-Fi transmission technology it is also possible to detect the presence of a person inside a building. By using the smart phone as a location device, we can triangulate the position according to the signal strength received from different access points (AP) (Curran et al., 2011). This type of technology makes it easier the use of mobile devices because these devices have connection interface for this type of networks. Because of this it is not necessary to install devices to adapt other technologies to (Wi-Fi). This feature helps the implementation of this type of systems due to the massive use of mobile devices by people including those with visual disabilities and WLAN IEEE 802.11 networks inside the home.

2.2 Indoor Positioning Techniques using Wi-Fi

Wireless location systems (WPS) based on the use of wireless local area networks (WLAN) have some advantages over other types of positioning systems due to most of the buildings and homes have available a WLAN infrastructure (Wen et al., 2011). Below we review various techniques that can find the estimated position of a person using WLAN and mobile devices.

Arrival time (ToA) and arrival time difference (TDoA), calculate the distance between the client device and the wireless access point (AP) based on measurements of time and signal speed between these points, the exact position is found by means of triangulation of signals (Yassin and Rachid, 2015). This type of technique requires a synchronization of equipment, a very stable connection and an algorithm for estimating the location of the individual, which would require a real-time location system server (RTSL) increasing the complexity and costs of the system. This makes it inappropriate for the development of the work described here because people with disabilities in Colombia generally have a very few economic resources requiring low-cost solutions.

The Arrival Angle (AoA) technique uses directional antennas to measure the arrival angle of signals transmitted by customers and the position is estimated through the geometry of the triangles by measuring the angles between the target and the reference nodes. An algorithm is required to calculate the estimated position with the data of the mentioned angles. The implementation would need a server in charge of this process increasing the costs and complexity of the system.

The received signal strength indication (RSSI) and the ”fingerprint” method are based on propagation models and associate the power levels of the customer’s signal with the distance between the customer and the AP access point (Yassin and Rachid, 2015). The strength of the client signal is measured from several access points and a propagation model is established based on this information to determine the position. There are two variants: one based on a map of RSSI vectors and another based on the calculation of signal loss by propagation. Therefore, an algorithm and a server are required to process the information and establish the propagation model, which would make the implementation of the technique more complex and expensive.

In the cell ID technique mobile devices are responsible for estimating which of the radio beacons is the nearest. This is done by scanning the radio propagation models or fingerprints to discover the nearest access point through its ID or MAC and therefore the position of the device in the network (Yassin and Rachid, 2015). It compares the received signals with those recorded in a database. Therefore, a server is required to register the data in a database. Table 1 shows a brief comparison between the techniques used.

In Colombia some works has been carried out to simulate interior positioning systems in order to compare the performance of a non-cooperative TDoA / DoA hybrid radio-location approach with a non-hybrid approach (Sanchez et al., 2018). This work corresponds to a simulation. Therefore, the system is not implemented and the hardware to be used is not set-up. Another work contemplates the design and implementation of a system for micro-localization by means of Wi-Fi wireless networks and low-power Bluetooth (BLE) technologies. The location of clients is based on a location algorithm performed with machine learning (ML) derived from the Signal-to-Noise Ratio (SNR) footprint method and the Received Signal Strength (RSS) (Terán et al., 2018).

In previous works, prediction models were used and localization algorithms were developed. This demanded the use of complex simulation scenarios for the first case and cloud servers in the second. The could increase the development costs of the mentioned projects. In this way the aim of the present work consists in developing a low-cost Domotic system for indoor location bringing conform for people with disabilities. For this, the mobile device was used as location equipment inside buildings as it is a device commonly used by people today. In addition, hardware such as an Arduino, a Router and a low-priced power board that easily available in the local market of small cities in Colombia were used.

In this way a Domotic system was developed that used a variant of the cell identification technique. This is focused on the detection of the nearest access point. As well, based on the comparison of the transmission power level of the nearby access points (AP), in that way the device established a connection with the one that provided a higher power level. Establishing a connection with it and with the local server configured in the Arduino.

3 SYSTEM OVERVIEW

The system consists of two local area networks (LAN) composed of a wireless router, an Arduino connected via shield (Wi-Fi) and the smartphone of the disabled person. Each LAN is an independent physical network operating in a specific area of the house and has its own IP block.

The Arduino was programmed as a web server for mobile devices. In this way we can know the position inside the house (IPS) of the disabled person and the location could be set according to the network to which the mobile was connected. The person received this information through a mobile application which in turn allowed the control of turning on and off appliances. A portable AC power interface was implemented, which connected to the home network and delivered the controlled AC signal to the appliances. The general scheme is shown in the figure 1.

4 EXPERIMENTAL TEST-BED SETUP

4.1 Hardware

The system was based on two LANs the first have a stationary node composed of a wireless Router, an Arduino with a shield (Wi-Fi), a power card with relays to control AC connection to supply household appliances. This node was located in a room and worked in standby mode in order to detect the presence of the mobile node (smart phone of the disabled person) and establish a Wi-Fi connection with it.

The objective was to develop an indoor positioning system (IPS) through Wi-Fi location. The second LAN works in the room and is composed by a stationary node and a mobile node with the same characteristics as those mentioned above.

At the stationary node an Arduino Uno was configured as a server. This has the function of send-

Table 1: IPS Comparison Table.

Category	Technique	Position calculation	Characteristics	Coverage
Time of arrival (ToA)	Time	Measurement of time and speed	Synchronization between devices	Indoor
Time of arrival difference (TDoA)	Time	Measurement of time and speed	Synchronization between devices	Indoor
Arrival angle (AoA)	Angle	Geometry of triangles	Requires special antennas	Indoor
Empirical Model	Received signal strength (RSSI)	Power levels	No special hardware needed for (MS)	Indoor
Fingerprint	Received signal strength (RSSI)	Power levels	No special hardware needed for (MS)	Indoor

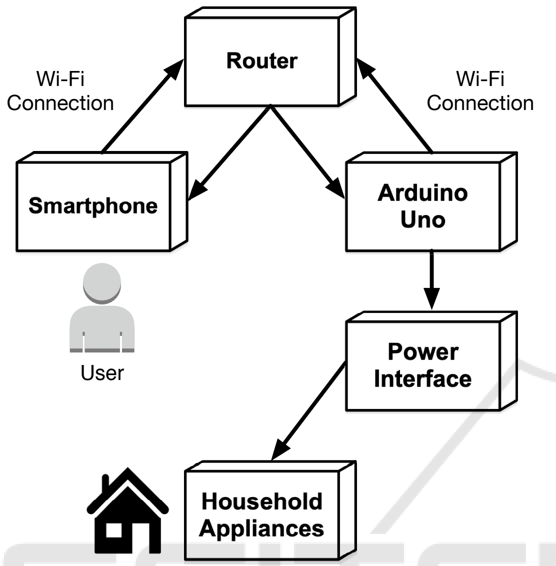

Figure 1: Block diagram of the domotic system - This figure shows the block diagram of the domotic system for people with disabilities. The smart phone can receive indoor location information from the Arduino located in each house area. It can also send on/off control signals to the household appliances.

ing messages wirelessly through the Wi-Fi extension board (shield Wi-Fi model R3) connected by SPI bus. This was responsible for processing and transmission of indoor location information and control on / off appliances. For the development of the domotic system the decision was made to use routers and create Wi-Fi subnets. Because of low cost equipment needed to implement this topology and the facility to find them in the local market. This guaranteed the viability of implementing the system in the homes of people with disabilities. To prevent the network overlapping problems, the Router's power transmission was reduced to minimum level. Also, no proximity detectors are used because the user only uses mobile equipment and it would be necessary to use additional hardware. The wireless router Tp-link TL-WR841ND acts as access point and interconnection between stationary node and mobile node for each of the LANs mentioned. The connection to the LAN was made through the Ethernet wireless standard IEEE 802.11b (Wi-Fi) by the nearest neighbor method based on the strength of transmission power.

The power module with 4 relay-controlled outputs was connected to the Arduino to receive the control signals transmitted from the mobile node. The purpose is to switching the alternating current loads connected to the electrical grid module (fan, television and luminaires). The elements described above were installed in a single module with the purpose of making it portable, allowing the location of the same in different areas of the house.

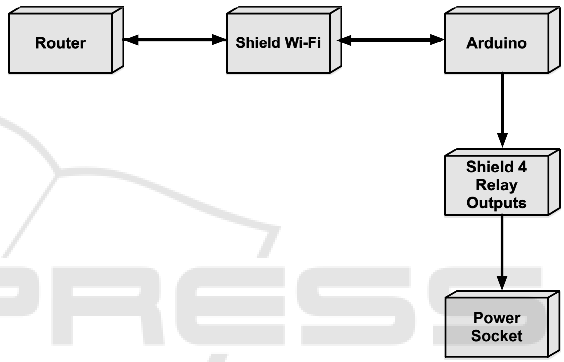

Figure 2: Hardware block diagram of the domotic system - This figure shows the block diagram of the domotic system hardware for people with disabilities. The Wi-Fi shield allows the Arduino to be connected to the subnet of the smartphone in order to receive the ON/OFF control signals from the appliances. The power card of 4 relay outputs is connected to the home network to allow the passage of AC current.

One of the advantages of the system is its easy configuration and the low implementation costs. The aim was to develop a tool that would improve the comfort of people with disabilities who are usually those with the lowest incomes rates in the case of Colombia. Figure 3 shows the hardware node.

The mobile node was based on a smart phone which had a mobile application developed for Android operating system. This allows the person in a situation of disability to receive spoken notifications of their position inside the home, operate the buttons to power devices and confirmation of the activation and deactivation of appliances.

4.2 Software

For the development of the mobile application an architectural pattern Model-View-ViewModel

Figure 3: Stationary node of a domotic system - In this image you can see the stationary node of the domotic system. It includes an Arduino connected to the Wi-Fi Shield, a router for the wireless connection to the subnet, a power card with 4 relays and a socket for the connection of household appliances.

(MVVM) was used. The layer view provides the graphical interface with the purpose of capturing the required requests and displaying the answers to the end user. Through this the visually impaired person received voice notifications about their position inside the house also controlled the switching on and off of appliances. Figure 4 shows the MVVM architectural pattern.

The model layer encapsulates the application logic and manages the wireless connection via Wi-Fi (IEEE 802.11) between the mobile device and the Arduino. It stores the data provided by the view, sends it to the Arduino for processing and returns the responses from the Arduino to the view model layer. It allowed the sending of data through objects of entities that represent actions executed or required by the persons.

Developed through the Arduino IDE and JAVA programming language, with the purpose of establishing the configuration method (Setup), inputs and outputs and establishing connection to the Wi-Fi network through the IP address and logical port. It allowed the storage of the network identifier (SSID) and password. To assign Wi-Fi channels, existing networks were scanned and the least used networks were selected.

At the first instance the view layer sends an object with the requirements of the disabled person to the logical view model layer. This took the object and transforms it to send the information to the model layer in charge of executing the user's request and responding to the view model layer confirming the execution of the request. This response was sent to the view layer so that the disabled person could receive a confirmation by voice or text. An image of the MVVM app and block diagram is shown below. Figure 5 shows the frontend of the App.

Figure 4: MVVM Block Diagram - In this image you can see the APP installed in the smart phone of the person in a situation of availability. This APP allows the user to receive confirmations about the interior location. It could also send on/off signals for the activation of household appliances. The user could recognize the graphical interface of the application using Google's APP Talkback.

5 EXPERIMENTAL RESULTS

The tests of the domotic system were performed by 11 visually impaired people, these developed inside the homes of people living in the city of Neiva. In each of the tests 3 routes were performed: route between a room and the living room, between room and kitchen, route between rooms. A total of 33 tests were performed with the purpose of tracking the change of internal position of the visually impaired person.

The tests involved the route of these individuals between two rooms of the house (points A and B). In each of these rooms had previously installed a stationary node: wireless router Tp-link TL-WR841ND, an Arduino UNO, a power interface connected to a

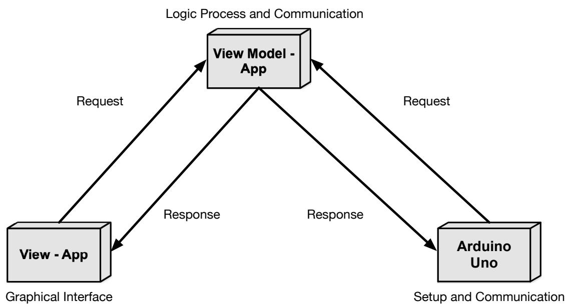

Figure 5: App graphical interface - This diagram shows the MVVM Model implemented in the development of software of the domotic system for people with disabilities. In the model layer the coding of the Arduino was implemented, in the view layer the code of the graphical interface of the APP was implemented and in the model layer the code necessary for the Wi-Fi connection processes of the system was implemented.

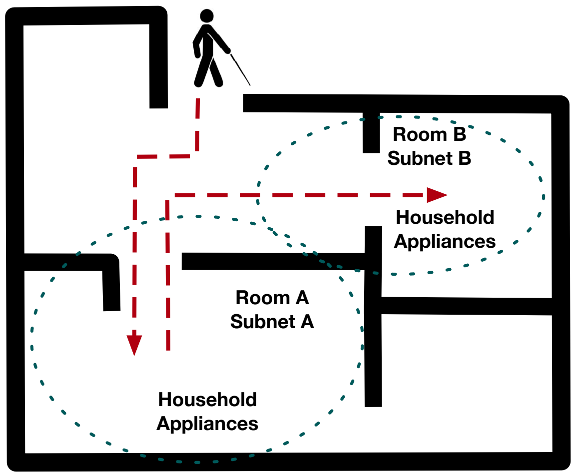

Figure 6: Schematic drawing of the tests performed - The test diagram shows the track made by the person in a situation of disability. The user moves from the room (A) and once identified in the subnet (A) could perform the activation of household appliances. Afterwards he left the room (A) and moved to the room (B) identifying himself in the subnet (B) and having the possibility of turning on household appliances.

power socket, to the latter were connected AC loads (television, fan and light bulb). Each time a test was carried out on a different route it was necessary to relocate and adjust the stationary nodes.

Therefore, each of these rooms (stationary node) had a wireless subnet provided by the Router. Thus, as the person moved between the rooms was connected to the different Wi-Fi networks through a smart phone (mobile node). As each room was approached, the server configured in the Arduino sent position information to the mobile device. Which through the APP generated warning and location voice messages such as "approaching the room" in order to guide the visually impaired person inside the home.

When the person entered the room A or B he has the control to power on or off the AC loads (TV, fan and bulb) by using the buttons arranged in the App. People with disabilities recognized the buttons through touch thanks to Google's Talkback application. Each time a section of the graphical interface is touched voice confirmations were generated about the name and function of each one of them. Figure 6 shows the diagram with the room distribution inside the house.

In addition, the App provided voice messages to confirm the activation or deactivation of appliances. When the person moved away from the room into which they had entered, confirmation voice messages were also generated such as: "leaving the room".

Once the tests of the domotic system were finished we proceeded to make an analysis of the performance of the same one. To evaluate the system, we had carried out several test. In this first phase the aim was to use a voice detection module to make it easier for visually impaired people to send control signals for switching household appliances on and off. Unfortunately, there were failures in the detection of voice commands and therefore it was not possible to send the control word to the stationary node.

Due to the problems with the detection of voice commands we opted for use Google Talkback application in order to facilitate the recognition of the interface and use the App by people with visual disabilities. In this way, the on/off control of household appliances worked correctly.

There were also drawbacks of high processing times and blocking of the interface when trying to establish connection to the network through the user interface (foreground). In order to solve this problem network connection methods were created that work in the background achieving a partial reduction in processing times for network access.

Likewise, there were problems with the wireless signal strength levels of the routers because the signals overlapped between those located in different areas of the house. As a solution, the output power levels of the aforementioned interconnection equipment were decreased.

5.1 Usability of the System

To determine the usability of the system a test plan was designed for people with visual and motor disabilities. The individuals who would perform the tests were selected and a basic questionnaire was proposed to be applied to the participants. In this way, the virtues and shortcomings of the system were determined in order to facilitate the movement inside the buildings and the control of the power on and off of electrical appliances for this type of population.

We performed 11 tests of approximately 2 hours each. The experiment consisted of 3 routes between different sectors of the house. Once the person was located in one of these points, it was possible to control the switching on and off of the electrical appliances. 18 tests, 54.5% of which were carried out on men and 15 (45.5%) on women. 21 tests (64%) were developed by people with visual disabilities and 12 (36%) by individuals with motor disabilities. This last group was included because in the execution of the project it was established that the system could also be useful for this type of population.

The operation of the domotic system (software and hardware) was analyzed. 7 (64%) of the people indicated that it worked correctly and 4 (36%) of the people informed of small deficiencies in the localization function. The process of user interaction with the mobile application interface was also evaluated. 6 (55%) of the individuals did not present significant usability problems and 5 (45%) of the individuals presented difficulties with the touch recognition. However, they indicated that with frequent use the results could be improved.

The system proposed here uses a mobile application that through the power level of the Wi-Fi signal allows to establish connection with the subnet of a specific area of the home and determine the interior position of the people with disabilities. Therefore, does not need the incorporation of special hardware in the mobile node compared to other systems that use ToA and AoA. This ensure that it is economical to implement. Also, does not use advanced technique of signal triangulation that allows it to be easy to implement by anyone.

To evaluate the satisfaction rate of use of the home automation system an interview was applied to people with disabilities that participated in the system testing. In the first place the usefulness of the home automation system for people with disabilities was questioned, with the purpose of asking people participating in the performance tests to express the possible benefits of using the system. It was also asked about the operation to know the effectiveness and possible failures of the system with the purpose of performing later adjustments. The use of the graphical interface was also investigated, the objective was to find out the possible operating problems to adjust it later. It was also asked about the type of disability to establish if the use of the system can be extended to another type of disability other than visual.

Figure 7 summarizes the satisfaction survey applied to the volunteers who tested the system.

Question	Yes	No
The home automation system is useful for people with disabilities	100%	0%
The home automation system works correctly	64%	36%
I have problems interacting with the graphical interface	45%	55%
Visually impaired	36%	64%

Figure 7: Survey Results.

6 CONCLUSIONS

For the development of the App it had to be considered that the disabled people who supported the present work did not have skills for the management of complex IT systems. Therefore, for the development of the application, simple controls were chosen by means of symbols, without using menus, dialogues or alerts.

In addition, for the proper functioning of the home automation system it was necessary for the App to establish a constant interaction with the visually impaired person, since in this way the user could have continuous information about their interior location and the appliances turned on.

It was also necessary for people with disabilities to have a period of adaptation to the application, in order to potentiate its operation and avoid situations of frustration due to possible failures of the system.

It is important to consider that the TP-LINK TL-WR841ND routers generated a low wireless transmission power, since a high level could cause identification errors of the subnet (area of the house) in the mobile device due to the superposition of signals from several routers, affecting the interior location of individuals.

It is expected in the future to be able to integrate the system to the home Wi-Fi network in order to avoid the installation of additional wireless routers, as a future option is considered to install Access Point Layer 2 and segment the broadcast domains through VLAN's. The advantage of this future adaptation consists in the fact that it is not necessary to install a different network to the domestic Wi-Fi, in such a way that it is not necessary to incur additional expenses for the development of the system.

One of the advantages of the domotic system proposed here is the use of smart phones as mobile nodes, because most people own one of these devices. Therefore it is not necessary for people to have additional devices for indoor location processes. It is only necessary to install the mobile application developed for the systems.

The tests were performed with only two appliances to test the functionality of the home automation system. However, it is expected to develop a system that includes a greater number of households appliances to be controlled from the application, which also should be reprogrammed.

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