escola superior de tecnologia e gestão
instituto politécnico de leiria

Dissertation

Master in Computer Engineering – Mobile Computing

Blind Guide: anytime, anywhere.

Daniel Augusto Vera Yánez

Leiria, September of 2017

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Dissertation developed under the supervision of Doctor Antonio Pereira professor at the School of Technology and Management of the Polytechnic Institute of Leiria and co-supervision of Doctor Diego Marcillo, professor at the Universidad de las Fuerzas Armadas - ESPE.

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- Yánez, D. V., Marcillo, D., Fernandes, H., Barroso, J., & Pereira, A. (2016, December). Blind Guide: anytime, anywhere. In Proceedings of the 7th International Conference on Software Development and Technologies for Enhancing Accessibility and Fighting Info-exclusion (pp. 346-352). ACM.

- Vera D., Marcillo D., Pereira A. (2017) Blind Guide: Anytime, Anywhere Solution for Guiding Blind People. In: Rocha Á., Correia A., Adeli H., Reis L., Costanzo S. (eds) Recent Advances in Information Systems and Technologies. WorldCIST 2017. Advances in Intelligent Systems and Computing, vol 570. Springer, Cham.

- Vera D., Marcillo D., Pereira A. (2017). Dispositivo de Navegación Portable para Personas No Videntes. In Information Systems and Technologies (CISTI), 2017 12th Iberian Conference. IEEE.

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Abstract

Sight dominates our mental life, more than any other sense. Even when we are just thinking about something the world, we end imagining what looks like. This rich visual experience is part of our lives. People need the vision for two complementary reasons. One of them is vision give us the knowledge to recognize objects in real time. The other reason is vision provides us the control one need to move around and interact with objects.

Eyesight helps people to avoid dangers and navigate in our world. Blind people usually have enhanced accuracy and sensibility of their other natural senses to sense their surroundings. But sometimes this is not enough because the human senses can be affected by external sources of noise or disease. Without any foreign aid or device, sightless cannot navigate in the world. Many assistive tools have been developed to help blind people. White canes or guide dogs help blind in their navigation. Each device has their limitation. White canes cannot detect head level obstacles, drop-offs, and obstructions over a meter away. The training of a guide dog takes a long time, almost five years in some cases. The sightless also needs training and is not a solution for everybody. Taking care of a guide dog can be expensive and time consuming.

Humans have developed technology for helping us in every aspect of our lives. The primary goal of technology is helping people to improve their quality of life. Technology can assist us with our limitations. Wireless sensor networks is a technology that has been used to help people with disabilities.

In this dissertation, the author proposes a system based on this technology called Blind Guide. Blind Guide is an artifact that helps blind people to navigate in indoors or outdoors scenarios. The prototype is portable assuring that can be used anytime and anywhere. The system is composed of wireless sensors that can be used in different parts of the body. The sensors detect an obstacle and inform the user with an audible warning providing a safety walk to the users.

A great feature about Blind Guide is its modularity. The system can adapt to the needs of the user and can be used in a combination with other solution. For example, Blind Guide can be used in conjunction with the white cane. The white cane detects obstacles below waist level and a Blind Guide wireless sensor in the forehead can detect obstacles at

the head level. This feature is important because some sightless people feel uncomfortable without the white cane.

The system is scalable giving us the opportunity to create a network of interconnected Blind Guide users. This network can store the exact location and description of the obstacles found by the users. This information is public for all users of this system. This feature reduces the time required for obstacle detection and consequent energy savings, thus increasing the autonomy of the solution.

One of the main requirements for the development of this prototype was to design a low-cost solution that can be accessible for anyone around the world. All the components of the solution can provide a low-cost solution, easily obtainable and at a low cost. Technology makes our life easier and it must be available for anyone.

Modularity, portability, scalability, the possibility to work in conjunction with other solutions, detecting objects that other solutions cannot, obstacle labeling, a network of identified obstacles and audible warnings are the main aspects of the Blind Guide system. All these aspects makes Blind Guide an anytime, anywhere solution for blind people.

Blind Guide was tested with a group of volunteers. The volunteers were sightless and from different ages. The trials performed to the system show us positive results. The system successfully detected incoming obstacles and informed in real time to its users. The volunteers gave us a positive feedback telling that they felt comfortable using the prototype and they believe that the system can help them with their daily routine.

Keywords: Internet of things; IoT; Mobile technology; Ambient assisted living; Ultrasound; Blind.

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Resumo

A visão domina nossa vida mental, mais do que qualquer outro sentido. Mesmo quando estamos apenas pensando em algo do mundo, acabamos imaginando o que parece. Esta experiência visual rica é parte de nossas vidas. As pessoas precisam da visão por duas razões complementares. Uma delas é a visão nos dar o conhecimento para reconhecer objetos em tempo real. A outra razão é a visão nos fornece o controlo de uma necessidade de se movimentar e interagir com objetos.

A visão ajuda as pessoas a evitar perigos e a navegar no nosso mundo. As pessoas cegas geralmente têm maior precisão e sensibilidade nos seus, outros, sentidos naturais de modo a sentirem o ambiente que os rodeia. Mas às vezes isso não é suficiente porque os sentidos humanos podem ser afetados por fontes externas de ruído ou doença. Sem qualquer ajuda externa ou dispositivo, sem visão, os cegos não podem navegar no mundo. Muitas ferramentas de apoio foram desenvolvidas para ajudar pessoas cegas. Bengalas ou cães-guia ajudam os cegos em sua navegação. Cada dispositivo tem a sua limitação. Os bengalas não podem avisar os utilizadores de obstáculos no nível da cabeça, drop-offs e obstruções acima de um metro de altura. A formação de um cão guia leva um longo tempo, quase cinco anos em alguns casos. O cego também precisa de treino e, para pessoas com baixos recursos financeiros, cuidar de um cão pode ser dispendioso.

Os seres humanos têm desenvolvido tecnologia para nos ajudar em todos os aspetos de nossas vidas. O principal objetivo da tecnologia é ajudar as pessoas a melhorar sua qualidade de vida. A tecnologia pode ajudar nas nossas limitações. As redes de sensores sem fios podem desempenhar um papel importante na ajuda de pessoas com deficiência.

Nesta dissertação, é proposto um sistema baseado nesta tecnologia denominado Blind Guide. O Blind Guide é um artefacto que ajuda as pessoas cegas a navegar em cenários interiores ou exteriores. O protótipo é portátil assegurando que pode ser usado a qualquer hora e em qualquer lugar. O sistema é composto por sensores sem fios que podem ser usados em diferentes partes do corpo. Os sensores detetam um obstáculo e informam o utilizador com um aviso sonoro, proporcionando uma caminhada em segurança aos utilizadores.

A modularidade é uma ótima característica do Blind Guide. O sistema pode ser adaptado às necessidades do usuário e pode ser usado em combinação com outras soluções.

Por exemplo, Blind Guide pode ser usado em conjunto com a bengala. A bengala deteta os obstáculos abaixo do nível da cintura e um sensor de guia cego sem fio colocado na testa pode detetar obstáculos ao nível da cabeça. Esta característica é importante, uma vez que algumas pessoas cegas se sentem desconfortáveis sem a cana.

O sistema é escalável, dando-nos a oportunidade de criar uma rede de clientes Blind Guide interconectados. Esta rede pode armazenar a localização exata e a descrição dos obstáculos encontrados pelos utilizadores. Esta informação é pública para todos os clientes deste sistema. Esta característica reduz o tempo necessário de deteção de obstáculos e consequente poupança de energia aumentando, deste modo, a autonomia a solução.

Um dos principais requisitos para o desenvolvimento deste protótipo foi o de criar uma solução de baixo custo que possa ser acessível a qualquer pessoa em qualquer lugar. Todos os componentes utilizados neste protótipo têm um custo reduzido. A tecnologia torna a nossa vida mais fácil e deve estar disponível para qualquer um.

A modularidade, a portabilidade, a escalabilidade, a capacidade de trabalhar em conjunto com outras soluções, a deteção de objetos que outras soluções não conseguem, a classificação de obstáculos, uma rede de obstáculos identificados e avisos sonoros são os principais aspetos do Blind Guide. Todos estes aspetos tornam o Blind Guide uma solução disponível, em qualquer altura e em qualquer lugar, para pessoas cegas.

Blind Guide foi testado com um grupo de voluntários. Os voluntários eram cegos e de diferentes idades. Os testes realizados no sistema mostram resultados positivos. O sistema detetou com sucesso os obstáculos recebidos tendo informado em tempo real aos seus utilizadores. A avaliação efetuada pelos voluntários foi positiva. Disseram que se sentiram confortáveis a usar o protótipo e acreditam que o sistema pode ajudá-los na sua rotina diária.

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List of acronyms

API	Application Programming Interface
CPU	Central Processing Unit
DNS	Domain Name System
GSM	Global System for Mobile communications
GPS	Global Positioning System
HTTPS	Hypertext Transfer Protocol Secure
IP	Internet Protocol
IoT	Internet of Things
JSON	JavaScript Object Notation
LAN	Local Area Network
LED	Light-emitting Diode
MQTT	Message Queue Telemetry Transport
RAM	Random Access Memory
SMS	Short Message Service
TCP	Transmission Control Protocol
XML	eXtensible Markup Language

Table of Contents

1 Introduction

Worldwide there are 39 million people who are legally blind and 246 million inhabitants that have low vision, totaling 285 million people with visual impairment. More than half of the visual impaired are aged 50 and above and live in low-income settings [1]. In Ecuador, the number of people with visual disability is around 48 thousand. Most of them are between 30 to 65 years, and only 13 thousand have a regular job [2].

Sight dominates our mental life, more than any other sense. Even when we are just thinking about something the world, we end imagining what looks like. This rich visual experience is part of our lives. People need vision for two complementary reasons. One of them is vision give us the knowledge to recognize things in real time. The other reason is vision provides us the control people need to move around and interact with objects [3].

The average visual impaired person is dependent on other people, or technology, to navigate in an unknown environment. When in an unfamiliar environment, blind people lack the knowledge about features and obstacles of the physical space around. They usually rely on tools like the white cane and the guide dog. However, these assistive tools have some limitations. The white cane has a maximum range of about 1,5 meters and only detects obstacles below the waist level. Guide dogs usually need long times for training, are very expensive and in most cases, it is tough for the blind to take care of the living dogs appropriately.

The primary goal of technology is to help people improve their quality of life. One such technology is the Internet of Things (IoT). IoT is based on a wireless network of sensors that communicate with each other to understand the environment and actuate when there is a change in their surroundings [4]. IoT depends in three fundaments: the users and their gadgets have a shared understanding of the situation, a software and networks

architectures to process and combine the information where is needed, and autonomous and smart behavior caused by the analytics tools of the IoT [5].

This work presents Blind Guide a system based on the IoT. The system is composed of wireless sensors (peripheral devices) that can be attached to any part of the body and a central device that has a camera and a speaker. When a wireless sensor detects an obstacle, sends a signal to the central device. The central device takes a picture and uploads the photo to an image recognition cloud service. Then the central device responds with an audible warning to the user. This signal contains the distance of the obstacle and the possible name of that object.

This modularity gives Blind Guide the flexibility of using the number of peripheral sensors as needed. With different configurations is possible to use Blind Guide with other solutions for user comfort.

Behind the system is a network that interconnects all the Blind Guide users. Sharing obstacle locations, making the system more reliable. This scalability cannot be found in other solutions. Making Blind Guide the first device for sightless people that shares information between each device.

Blind Guide is a low-cost solution because all the different materials used to make the prototype are cheap and easily obtainable around the world. All the previously described features make Blind Guide an anytime, anywhere solution. The prototype has been tested with volunteers with different degree of visual impairment and environments.

1.1   Objectives and Contributions

The goal of this project is to make a portable electronic device that helps sightless people in their navigation in indoors or outdoors. Blind Guide improves the quality of life of its users. The following chapters present an architecture of the system based on the wireless sensors networks. Many field test with blind people were performed to adjust and validate the solution. In the end, present a low-cost portable device that helps visually impaired to detect and avoid incoming obstacles in an indoor/outdoor scenario. The main contributions of this dissertation are presented below.

Investigation of Blind People Needs.

The first contribution of this project was an investigation of the different needs and limitations that visually impaired have. The research also included the existing devices

for blind people and the advantages and disadvantages of that devices. The architecture of Blind Guide is shown in chapter four of this work.

Proposal for an Architecture for Blind Guide.

The second contribution was the design of the architecture for Blind Guide. This architecture incorporated successful ideas from previous investigations from research teams around the world. The primary goal was to develop a wireless architecture to be more comfortable for the users.

Prototype of the Proposed Architecture of Blind Guide.

The development of the first prototype was the third contribution. Gathering different materials and make them work together to achieve the desired functionality. The peripheral sensors were designed to use wireless communication with the central device. The different devices and technologies used in this prototype are presented in chapter three and the architecture of the system is shown in chapter four.

The methodology utilized for this project was software prototyping. The idea of this method is to develop a prototype and then validate with the final users. Results of the validation are feedback from the final users. With this feedback, the development team can prove if the goals of the project were satisfied with the prototype. If the feedback was negative, the team make adjustments to the prototype and then validate it. The cycle repeats until the final user is satisfied with the prototype. After that, the final product is produced. This methodology is useful for achieving the objectives of this project.

1.2 Dissertation Structure

To achieve the objectives presented in the previous section this dissertation is structured in the following way. In Chapter 2, shows the reality of the visually impaired in the world and the situation in Ecuador. Also, several sensor-based solutions that had already been made in the past for different research teams all over the world. In chapter 3, technologies used with the proposed system are discussed. Chapter 4 describes the Blind Guide implementation. In chapter 5, results of the tests performed in visually impaired using Blind Guide are presented. Finally, in chapter 6 some final considerations are given, as well as directions for future work.

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2 Technologies for sightless

The first section of this chapter presents the facts about sightless people around the world and the reality of blind people that live in Ecuador. After the reality of blind people around the world comes the section where the technologies in whose Blind Guide relies on are presented, compared and explained. Finally, different studies of devices for the sightless from other research teams are presented at the end of this chapter. Before the idea of Blind Guide was consolidated an extensive study of different scientific papers was made. These papers present different technologies for helping blind people. Learning about the experiences and complications that the research teams had, help us to understand the needs that sightless have. A brief resume of the scientific articles that help us to develop Blind Guide solution impaired is present in this chapter.

2.1 Blind people around the World

As reported by the International Classification of Diseases there are four levels of visual function:

- Normal vision;
- Moderate visual impairment;
- Severe visual impairment;
- Blindness.

Excluding normal vision, the others represent all visual impairment. The term "low vision" is the combination of moderate and severe visual impairment. In the world, there are around 39 million people that are blind, and 246 million have low vision. A total of 285 million inhabitants that are visually impaired. Most of them are aged 50 and above and live

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in low-income settings. The common causes of visual impairment according to the World Health Organization are:

- Uncorrected refractive errors (myopia, astigmatism), 43%;
- Unoperated cataract, 33%;
- Glaucoma, 2%.

Blindness caused by infectious diseases has reduced in the last 20 years. Almost all visual impairment can be prevented or cured. Cataracts are the leading cause of blindness in middle and low-income countries.

Children and people aged 50 and over are the two most likely social groups to visual impairment. Refractive errors, a condition that could be easily corrected cause visual impairment in 12 million children. The elderly population is increasing in many countries. This social group will be at risk due to chronic eye diseases and aging processes.

2.2 Ecuadorian Reality

In Ecuador, there are around 400 thousand people with an impairment. Most of the impaired are aged 30 and over. This information is illustrated in the next table.

Age	People
0 to 3	3, 778
4 to 6	7, 687
7 to 12	24, 203
13 to 18	31, 030
19 to 29	55, 575
30 to 65	194, 964
65 and over	90, 784
Total	**408, 021**

Table 2.1 - Visually impairment by age.

The following chart shows how this group of people is divided by their impairment.

Impairment	People
Hearing	51, 875
Physical	193, 520
Intellectual	91, 651
Language	5, 614
Psychological	7, 690
Psychosocial	9, 675
Visual	47, 996
Total	**408, 021**

Table 2.2 - Impairment groups.

In Ecuador, there are around 50 thousand sightless people most of them are 30 and over. Only the 8% of all the impaired have a complete education this results that only the 22% have a regular job.

All this data tells us that most of the blind in Ecuador have a low-income setting. For this cause, acquiring tools for the blind is more difficult for this group. That is why a low-cost solution for sightless people made with easy to obtain materials is needed. This solution must help them with their daily routine.

2.3   IEEE 802.11 wireless LANs

Local-area Networks (LANs) are used to connect data users via wire or cable in local areas that have a few kilometers. The IEEE developed the IEEE 802 standard. This specification provides some rules for communication in small areas. The most famous of these standards is 802.3 or Ethernet. Ethernet used wires to interconnect the data users. [27]

The wireless Ethernet IEEE 802.11 maintains some characteristic of the 802.3 Ethernet standard. The medium of transmission is mushed less reliable than wired media. The propagation properties can be asymmetric and time-varying. Also, lacks full connectivity and user stations may not always be able to hear each other. [27]

The most popular wireless networking technology based on the IEEE 802.11 standard is Wi-Fi. Wi-Fi uses radio waves to provide wireless high-speed Internet and network connections. In Wi-Fi networks, the link between the sender and the receiver is by

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radio frequency technology (RF). The sender and receiver are provided to an antenna that creates an electromagnetic field that can propagate through the air. [27]

The devices that are compatible with Wi-Fi specification are personal computers, smartphones, video game consoles, cameras, tablets, smart watches. The number of devices that support this standard is increasing day by day.

To provide Internet access and network communications, the Wi-Fi specification uses the Internet protocol suite that is composed of the combination of two protocols Transmission Control Protocol (TCP) and the Internet Protocol (IP). This protocol provides rules to how the transmitted data should be packetized, addressed, transmitted, routed and received. [27]

As most of the protocols the Internet protocol suite is structured in layers. Each layer represents data transfer operations. The layers are defined by the Open Systems Interconnect (OSI) Reference Model designed by the International Standards Organization (ISO). The OSI Reference Model defines seven layers that are listed below.

No.	Layer Name	Description
7	Application	Services that are used with end user applications.
6	Presentation	Ensures that the information is delivered to the receiving machine in a form that can understand.
5	Session	Starts and ends session between two hosts and also keeps them isolated.
4	Transport	Manages the transfer data and assures that received and transmitted data is identical.
3	Network	Reads the IP address from the packet.
2	Data link	Handles the transfer of data across the network media.
1	Physical	Network Interface cards – Electric Signals.

Table 2.3 - OSI Reference Model layers.

The Internet protocol suite (TCP/IP) uses some of OSI model layers and combines others. The protocol stack of TCP/IP has five layers that are listed below.

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No.	OSI Layer Equivalent	Layer Name	Protocol Examples
5, 6, 7	Application, Session, Presentation	Application	SMTP, FTP, Telnet, ssh, etc.
4	Transport	Transport	TCP, UDP
3	Network	Internet	IP, ARP, ICMP
2	Data link	Data link	PPP, IEEE 802.2
1	Physical	Physical network	IEEE 802.3, Token Ring, RS-232, etc.

Table 2.4 - TCP-IP Protocol stack.

The Wi-Fi stander uses frequencies between 2.4 GHz and 5 GHz. The range of connection is approximately 50 meters. The data transfer rate is maximum 600 Mbps, but typically is between 150 to 200 Mbps. This depends on the channel frequency and the number of antennas. Latest 802.11-ac standard should offer 500Mbps to 1Gbps. [27]

2.4 Wi-Fi Direct

Wi-Fi Direct is a technology created by the Wi-Fi alliance the primary goal for Wi-Fi direct is to enable a direct device to device communication over Wi-Fi. Wi-Fi direct used the same technology as IEEE 802.11 devices use to communicate with wireless access points. Devices with this technology function as access points and other devices can connect directly to it using WPA2 encryption. [31]

The speed of Wi-Fi direct can reach 100-250 Mbps in a range approximately to 60 meters. The power consumption of a device using Wi-Fi direct depends on the time and range of the connection. [31]

2.5 Bluetooth Low Energy

This technology is popular among gadget makers because the primary operating systems for computers or smartphones support Bluetooth low energy. Making easier for the customers to use the product.

The main differences between Bluetooth 4.0 and the previous versions are: [29]

- The client/server architecture was redesigned to ease the implementation and have lowest cost;
- Data can be retrieved at any time by a customer;

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- Design for small and discrete data transfers;
- Simplification of the discovery and connection.

For a BLE that wants to be visible to the outside world the Generic Access Profile (GAP) is used. GAP controls the links, the advertising in Bluetooth and determines how two devices can or can't send data to each other. [30]

GAP also defines roles for the devices the primary functions are: [30]

- Central: the device that has the biggest processing power and memory such as mobiles phones, tables, computers;
- Peripheral: devices that are resource constrained and low power that can connect to a more powerful device.

GATT (Generic Attribute Profile) defines the way that BLE devices transfer data between each other. GATT uses Services and Characteristics. This profile makes use of the Attribute Protocol (ATT), a data protocol that is used to store services, characteristics and related data in a table using 16-bits IDs. [30] In BLE connections are exclusive. That means that a BLE peripheral can only be connected to one central device. When the connection is established the device stops advertising itself and is no longer visible. [30]

Bluetooth low energy offers two topologies broadcast network topology and connected network topology. Each one works in a different way and are for different purposes. [30]

Broadcast Network Topology is used to advertise data. This topology is used when the requirements of the BLE device says that has to send data to more than one device at a time. This is possible using the advertising packet. Adding a small amount of custom information in the 31 bytes advertising or scan response payload, the BLE device is able to send data to any devices in listening range. With this topology, the devices can send the same data multiple times to different devices. [30] This topology is illustrated in the image below.
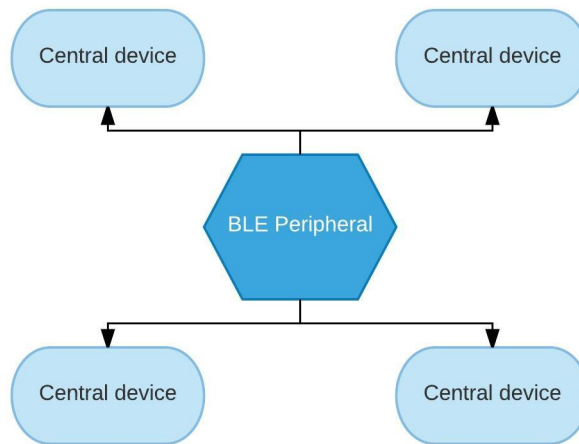
Illustration 2.1 - Broadcast topology.

When data needs to be exchanged between BLE devices the Connected Network Topology is used. As soon as the link is established between the peripheral and central device, they can have a both ways communication. A Bluetooth low energy peripheral can only be connected to a BLE central at a time, but the central can be attached to multiple BLE peripherals. [30] The illustration 2.2 shows how this topology works.
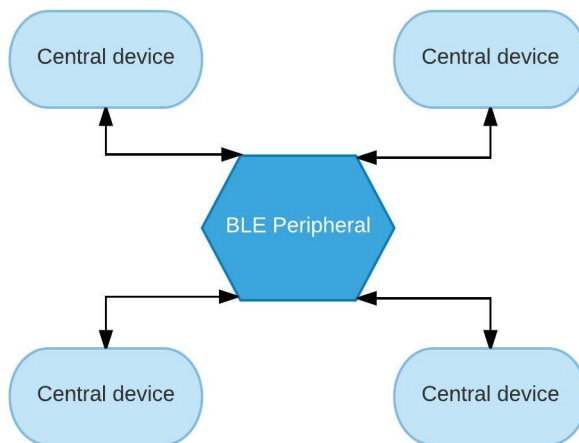
Illustration 2.2 - Connected topology.

GATT has clients (phone, table) and servers (peripheral devices). All the transactions are stated by the master device (GATT client), which receives response from the slave device (GATT server). When the connection is establishing, the peripheral will suggest a connection interval and the central device will try to reconnect in that range to see if there is any new data. This time is only a suggestion the central device decides when to reconnect. [30]

GATT transactions are formed by objects called Profiles, Services and Characteristics. The profile is a collection of services and it does not exist in the peripheral. Services are used to break information up into logic entities called characteristics. A

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service can have one or more characteristics. Each of these services is identified by a unique numeric ID called UUID, which can be 16-bit or 128-bit.

A characteristic encapsulates a single data point. Each characteristic is also defined by a 16-bit or 128-bit UUID. Characteristics also can be used to send data to the peripheral device. [30]

2.6 Bluetooth Low Energy vs Wi-Fi Direct

Each technology has its pros and cons and the one that someone should prefer using in a project depends on the requirements of that project. The following table shows a comparison between this two technologies.

Wireless Standard	Speed	Range	Power Consumption
Wi-Fi Direct	100-250 Mbps	~60 meters	high
Bluetooth Low Energy	1 Mbps	~15 meters	low
Bluetooth Classic	2-3 Mbps	~15 meters	high

Table 2.5 - BLE vs Wi-Fi Direct.

2.7 Internet of Things (IoT)

The next step in computer technology will be far from the traditional desktop. A network of interconnected devices gathering and sharing information is the IoT paradigm. New web technologies are being developed to store, process and present a significant amount of data that the interconnected devices will create. [4]

The growing presence of Wi-Fi and 4G-LTE wireless Internet access is vital for creating an IoT network. The devices in these systems will be more than just smartphones and tablets. Such devices will be existing everyday objects that in the past were working in isolation. [4] This growing number of appliances will create a smart environment. This environment will help people to be more productive, healthier and safety. IoT relies on different technologies some of them are listed above. [4]

2.7.1 Radio Frequency Identification (RFID)

RFID technology allows microchips to communicate wirelessly. This communication is formed by two parts the reader and the tags. When they are close enough, the transmission will start. [4]

There are passive RFID tags that do not require a battery. These passive tags activate and communicate when a reader is close. This technology is being used in many applications such as transportation, banking, supply chain management. [4]

2.7.2 Wireless Sensors Networks (WSN)

Thanks for the advances in low power integrated circuits and wireless communications now is possible to have small devices for use in remote sensing applications. [4] A Wireless Sensors Networks consist of a wireless network of autonomous distributed devices. These devices use sensors to monitor weather or physical conditions. A WSN also has a gateway that provides connectivity to the devices to gather information from them. [4]

WSN can be applied in a great variety of areas including health care, essential services, and remote monitoring. For basic services such as electricity, street lighting, and water councils, wireless sensors offer a low-cost method for a healthy data collection system that helps reduce energy use and better resource management. In health care, wireless devices make the monitoring of patients and possible health care less invasive. Remote control applications include environmental monitoring of air, water, and soil, structural monitoring for buildings and bridges, industrial monitoring of machines. [4]

WSN primarily uses three types of network topologies. Star topology, each node connects directly to the gateway. Tree topology, each node connects to a higher hierarchy node in the tree and then to the gateway, data is routed from the lowest hierarchy node in the tree to the gateway. [4] Finally, to provide greater reliability, mesh networks, the characteristic of this topology is that nodes can be connected to multiple nodes in the system and pass the data by the available path of greater reliability. [4]

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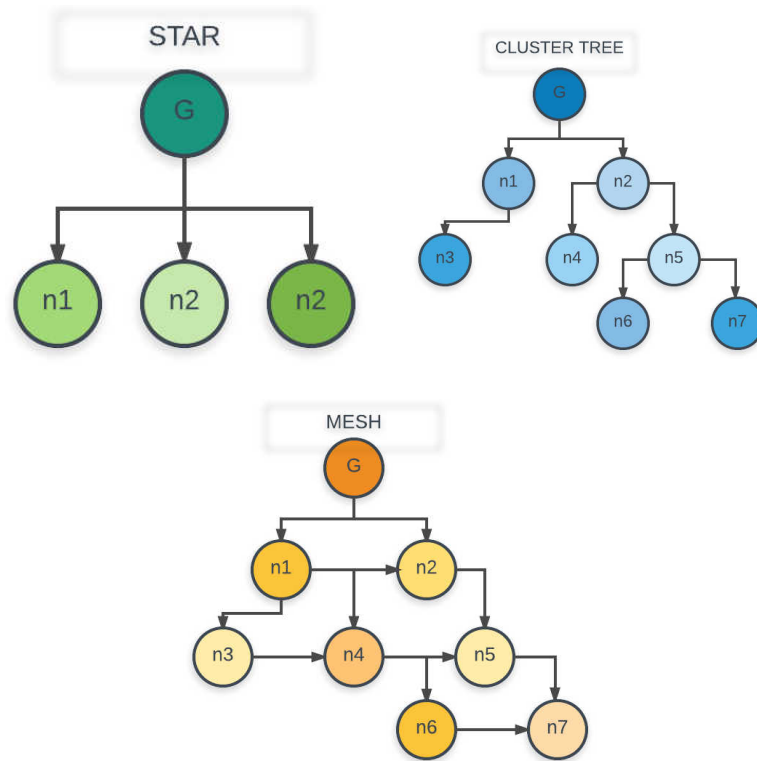
Illustration 2.3 - WSN Topologies.

2.8   Internet of Things Data Protocols

IoT is not a new technology but a defined IoT architecture has not been defined and there is not common agreement in standards and protocols. Making the spread of IoT worldwide difficult. [31] This section show us the most popular protocols for exchanging information in IoT.

2.8.1 CoAP

A synchronous request/respond application layer protocol called Constrained Application Protocol (CoAP) developed by the Internet Engineering Task Force (IETF) is used for information exchange in constrained-recourse devices. [31]

CoAP is a UDP-based application layer protocol. UDP allows CoAP to reduce overhead, the bandwidth requirements and allow CoAP to be unicast and multicast. The client-server architecture is based in the HTTP commands GET, POST, PUT and DELETE to give resource-oriented interactions. CoAP responses can be synchronous and asynchronous. [31]

In order to provide Quality of Service (QoS), CoAP uses four different kinds of messages for the communication: [31]

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- **Confirmable:** A message that requires an acknowledgement (ACK). The response can be in a synchronous or asynchronous way;

- **Non-Confirmable:** Message that not require ACK;

- **Acknowledgment:** The confirmation of the message reception;

- **Reset:** The received message could not be processed.

CoAP does not includes any built-in security features. Datagram Transport Layer Security (DTLS) can be used to secure the communication. DTLS provides authentication, confidentiality, data integrity and cryptographic. The use of DTLS with CoAP removes to option of multicast. [31]

2.8.2 MQTT

Message Queue Telemetry Transport (MQTT) is a protocol for M2M (machine to machine) communications created by IBM. Uses TCP protocol in an asynchronous publish/subscribe way. In this way clients do not have to request for updates reducing network bandwidth and the use of computational resources. MQTT ensures reliability by using three QoS levels: [31]

- **Fire and forget:** The message dos not need ACK;

- **Delivered at least one:** The sent message requires ACK;

- **Delivered exactly once:** A way to ensure that the message was received at least once using four-way handshake.

Using a publish/subscribe architecture MQTT lower the bandwidth and the processing extending the battery life of the devices. To provide security MQTT uses TLS/SSL (Secure Sockets Layer). [31]

2.8.3 XMPP

XMPP (Extensible Messaging and Presence Protocol) is an old protocol that is widely use all over the Internet. Uses TCP and provides two different systems: request/response (synchronous) and publish/subscribe (asynchronous). XMPP was designed for real-time communications and provides low latency exchange and small footprint. [31]

XMPP ensures reliability using the TCP mechanism and do not provide QoS options. TLS/SSL is used to give security to XMPP. In XMPP the messages are in XML (eXtensible Markup Language) format that creates an overhead and the devices need

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additional computational power to process the message leading to more power consumption. [31]

2.8.4 Restful Services

The architectural style Representation State Transfer (REST) is widely used all over the internet. REST uses the methods GET, POST, PUT and DELETE from HTTP to exchange messages in a synchronous request/respond way. The message contains the header of HTTP and the content can be XML or JSON (JavaScript Object Notation). This style can be easily configured in all operating systems and all M2M cloud platforms support it. [31]

REST uses TLS/SSL for security. The use of HTTP means that REST does not support constrained-communication devices and only can be used for final applications. CoAP is a light version of REST that has the capability to be used in constrained resource devices. [31]

2.8.5 AMQP

Financial industry uses the TCP based Advance Message Queuing Protocol (AMQP). This protocol provides an asynchronous publish/subscribe communication. The key feature of this protocol is to ensure the reliability even after network problems. The messages that AMQP uses are:

- **At most once:** The message is sent one time if does not matter if was received or not;
- **At least once:** The message will be received at least one time;
- **Exactly once:** The message will be received at exactly one time.

AMQP uses TLS/SLL for security. The success rate of this protocol depends of the bandwidth. Low bandwidth means low success rate. [31]

2.8.6 Websocket

Websocket is a protocol based on TCP. Was created as a part of HTML 5 for message exchange in an asynchronous full-duplex connection. The handshake is similar of HTTP but after the connection is stablished the HTTP header are removed and the devices can communicate in real-time and full-duplex way. [31]

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This protocol runs over the reliable TCP and implements no reliability mechanisms by its own. If required, the communication can be secured using the Websocket over TLS/SSL. A sub-protocol of Websocket provides a publish/subscribe system and is called WAMP (Websocket Application Messaging Protocol). [31]

This protocol was not designed for the use in resource constrained devices. However, was designed for real-time communication, Websocket is secure, minimizes overhead and with the use of WAMP can provide efficient communication. [31]

2.9   Assistive Technologies

Many teams for different parts of the world have been developing different systems with the purpose of help visual impaired with their daily lives. One of these solutions is an information system based on location data used to guide blind people, called BlindeDroid. BlindeDroid is a software library in Java for Android mobile devices. The team developed a prototype based on this library and tested it on a shopping center with two blind people.

The prototype gathers the information required importing XML files from beacons placed in strategic locations inside a building. With this information, the prototype helps the user with guided navigation, answering questions and providing objective information about places, products, and services near the user. The system gives the possibility to create a personal beacon network with information such as stores, services, houses. The system a significant number of tags to successfully help their user with the navigation. Although this drawback, BlindeDroid was able to help the testers to reach their desired location in the test perform by the research team [6].

In [7] the authors propose a smart walker that helps visually impaired people with walking disabilities. This research team decided to elaborate this prototype because almost all the products for visually impaired are not meant to be for people with walking problems. The prototype is a walker that does not only provide walking assistance but also helps the user avoiding obstacles. The system detects obstacles such as curbs, staircases, and holes in the ground and transmits obstacle proximity information through haptic feedback.

The positive and negative obstacle detection is performed by two lasers. The data from this laser is combined and processed by a central computing device. When an obstacle is detected is transmitted via Bluetooth to a belt that the user is wearing. This belt

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has five vibrating motors to provide haptic feedback. Each engine covers 45 degrees; all combined makes a total of 225 degrees of coverage.

The authors tested a prototype of the smart walker at SightCity 2014 in Germany. They received positive feedback. The tester said that the smart walker makes them feel safe. The prototype successfully detected all the obstacles in the test. The illustration below shows the smart walker prototype with the haptic belt.
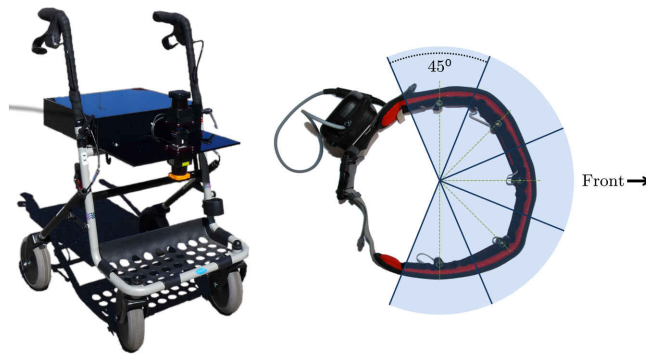
Illustration 2.4 - Smart Walker and haptic belt.

In the paper [8] the authors sought to design specifications that detail how to build a service robot that could interact and guide a visually impaired person through a building in an efficient and socially acceptable way. The research team said that robots are becoming more common in large buildings like hotels, stores and airports. As bear out in [23], that tells us about a robot officer used for patrolling city's malls and tourist attractions in Dubai. A robot officer is a great tool for police as it can broadcast any incident directly to headquarters, helping with a quick response.

The authors of [8] conducted participatory design sessions with three designers, two of them with vision disability and five visually impaired non-designers. Authors assure that using a robot for indoor navigation has two main advantages. Interacting with robots will require minimum training. The robot will provide information depending on the needs of the person that is requesting help. It can only provide directions for people that are familiar with the environment or escort the person. The escort action can be walking next to the visually impaired or slightly ahead; this depends on user comforts.

Second, they assume that robots will be designed for multiple activities and they will require minimum changes to assist blind people. At the end of this study, the authors developed design recommendations for a blind people guiding the robot. They hope that their study will inspire robotics researchers to make a prototype. Illustration 2.3 shows the interaction between a blind person with the guiding robot.

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Illustration 2.5 - Guiding robot.

Another indoor navigation system for sightless people uses visible light communication [9]. In this system, LED lights, a smartphone with integrated Bluetooth, a visible light receiver and headphones were used for the implementation. The system employs LED lights and a geomagnetic correction method [9].

Each LED light has an identifier. The light ID is sent via a light communication channel to the smartphone receiver. This receiver transmits the ID of the LED to the phone via Bluetooth. Using the LED light, the phone receives the positional data from a cloud service, via Wi-Fi. The positional information is combined with the guidance content into audio files and transmitted to the user's headphones [9].

A big challenge for this project is to identify the direction of the user inside a building. The authors used the geomagnetic sensor of the smartphone, but the data were coming from this device can be distorted by in indoor spaces. They make corrections using geomagnetic data taken in advance for each LED light.

The prototype was tested with six volunteers inside a building. Three of them with low vision and three blind. The volunteers had to travel from the reception of the building to the toilets. The average time that the volunteers take to reach destination was five minutes. After the test, an interview with each subject was conducted. All the volunteers told the interviewer the system needs to be more accurate in the direction and fix the timing of the guidance. As conclusions of the publication, the authors said that the prototype could guide a person inside an unknown building, but a better system for detecting the direction in indoors is required. The system also lacks of the ability of detecting obstacles that is an important feature for all guiding systems. The following illustration shows how the system works.

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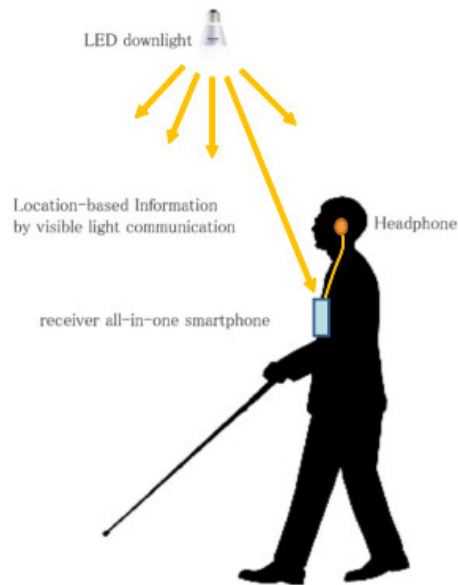
Illustration 2.6 - Indoor navigation using visible light.

The authors of paper [10] developed a camera-based assistive text reading framework to help visually impaired read text labels and products packaging from hand-held objects in their daily lives. The recognition software locates the text region and distinguishes the words. The recognized text codes are output to blind users in an audio form [10].

The proposed system uses a new way of detecting the region of interest by isolating the object using movement. The user has to shake the object with this the systems identify the object that has to read the text. This approach is helpful in environments like supermarkets or shopping malls. Different kinds of algorithms for detecting text are implemented in this device. The reason of this is because commercial products use different patterns for labeling their products to be more attractive to possible consumers.

The experiments performed in the recognition software demonstrate that achieves state of the art. The authors found interface issues and some problems in extracting and reading text from different objects with complex backgrounds [10].

Virtual Eye uses GPS for helping sightless people [11]. The prototype consists of a GPS receiver, GMS module, a microcontroller (ATMEGA 328), an ultrasonic sensor, a speech IC and headphones [11]. When the ultrasound sensor finds an obstacle, sends the information to the microcontroller. The microcontroller processes the data and when an obstacle is found a signal is forwarded to the speech IC.

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The speech IC inform the user that an obstacle is detected by a sound. The GPS information is continuously sent to the microcontroller. The microcontroller transmits the location using the GSM modem in SMS format to all saved numbers. If a familiar of the blind person wants to know where the user is can send a text message to the device number and the system will answer with a text message with the coordinates of the blind person.

This system uses low-cost materials that can be acquired easily. The primary goal of the authors is making an inexpensive solution for visually impaired. As reported in the begging of the present chapter a large quantity of the blind population around the world lives in a low-income setting.

In [21] the authors created a virtual eye system for guiding users in indoor and outdoor. Their system consists of two cameras mounted in the forehead of the user. The cameras transmit real-time video through a USB connection to a DPU (Data Process Unit) in this case the authors used a laptop. The laptop has a real-time recognition software. The prototype can detect and identify free paths, moving obstacles that may interfere the free path, stairs, crosswalk and traffic lamps.

Before the recognition process takes place. The images from the cameras pass a preprocessing stage. This stage has three parts image acquisition, rectification, and stabilization. This process improves the accuracy of the detection. The recognition workflow starts with the free path identification. The open path detection algorithm compares similar pixels in the bottom part of the image identifying the route that the user is following in a few meters ahead. This algorithm is not perfect caused by head movements and holes in the path; the authors encourage to find a more robust algorithm.

After that, the system starts identifying ground level. The purpose of ground level detection is to eliminate walls and objects that are not on the ground level. The algorithm makes the assumption that the ground is the large plane of the image. In the majority of the cases, this is true except when the user is in front of a wall. With the ground level detected the prototype could start identifying stairs and crosswalks. Once a stair or crosswalk is discovered the program starts looking for traffic lights.

All the processed information is transmitted to the user using audible alerts. The designers reduced the signal generation as low as possible. The reason of this is because visually impaired rely mostly on their hearing.

The authors tested the system and concluded that the system needs about two minutes of training. They tested the solution with visually impaired people, and most of them gave positive feedback. A small group said that the solution is loud and depriving.

BIOH uses ultrasound in order to detect obstacles [22]. This ultrasound system is placed in the forehead of the user. When an obstacle is detected, the system gives a pressure warning in the forehead of the user. The intensity of the pressure depends on the distance to the obstacle.

The prototype can be combined with a GPS and 3G module. This module offers the possibility to add a SOS button. When the user needs help can press the buttons and the system sends a text message with the location of the user to predefined numbers.

The authors believe that the system can be improved using solar energy for places with lower accessibility.

Another study related to this project is Smart Vision. Smart Vision consists of an ARM7 LPC2148 microcontroller, a camera, a computer, a GPS and a speaker. The focus of this study is the development of a computer vision module for Smart Vision. The system uses synthetic vision to detect obstacles that are alerted to the user through audible signals [24].

GPS (Global Positioning System) is used for outdoor navigation. Coordinates of several locations are stored in the microcontroller, and when the user reaches the desired position, he/she will be alerted by the speaker [24]. Smart Vision showed that it could detect obstacles by helping the blind to move without help from another person [24].

A study for blind people following a path indoors using the camera of a smartphone is presented in [25]. Eight visually impaired volunteers participated in this study. In which three different tests were performed to find markers with the camera of the smartphone [25].

The authors used readily detectable markers that did not require a significant computational processing [25]. As conclusions of this study, the authors highlight three aspects. The limited field of view of the camera of the smartphone caused the scan to be more active, which is hard for some people. Some of the participants found uncomfortable carrying the cell in their hand so the authors recommend exploring the option of cameras that can be attached to the body [25].

Finally, it was found that despite using markers for easy detection find them can take quite a while in certain environments. This means that the setting and location of markers is essential [25].

In [26] the authors explore different ways of making visual maps to be used by blind people. They give as an example of a website to book hotels. In which you enter the dates of stay, and the city you want and the page show on a map the hotels that exist in the place [26].

To make this page accessible, the authors recommend small modifications to existing functions. For example, when the mouse passes a hotel the name and information are displayed. You can add audio with the same information.

By adding compatibility with touch screens, the web page can be easily accessed [26]. The authors state that their study may be the starting point for creating new technologies for the blind [26].

There are many systems related to the works presented in this work. We believe that our blind guide solution has extra value than the rest as it uses an image recognition software that will help sightless people to understand their surroundings. We also pretend to give social skills to the systems to create a database that stores the location of the obstacles and make it available to the rest of the users of our system.

2.10 Synthesis

In this chapter, a study of the scientific knowledge in the area of the IoT was carried out, in which this work is based. It was intended to make known the challenges and possible solutions and trends.

In the first part of the chapter, statistics about the reality of visually impaired in the world and Ecuador. There is around 285 million of the blind, most of them are aged above fifty and live in low-income settings. This first part contains the most common diseases that cause visual impairment, some of them are treatable, but for lack of resources, people don't have access to medical resources.

The second part of the chapter was about the concept of IoT and the technologies on which it is based and relies on. The section includes the description of Wi-Fi and Wi-Fi Direct and how these technologies help in the communication device to device, an essential part of IoT. Bluetooth Low Energy is another technology focused in resource constrained

devices that help in their communication. The differences of Wi-Fi Direct and Bluetooth Low Energy was described. Each technology has their advantages and disadvantages, and the main reason for choose one or another is the requirements for the project.

IoT has a many data protocols that help devices communicate with others. Each protocol provides communication in different ways, the next table is a summary of the data protocols of this chapter. [31]

Protocol	Transport	QoS options	Architecture	Security
CoAP	UDP	YES	Request/Response	DTLS
MQTT	TCP	YES	Publish/Subscribe	TLS/SSL
XMPP	TCP	NO	Request/Response Publish/Subscribe	TLS/SSL
REST	HTTP	NO	Request/Response	HTTPS
AMQP	TCP	YES	Publish/Subscribe	TLS/SSL
Web socket	TCO	NO	Client/Server Publish/Subscribe	TLS/SSL

Table 2.6 - Major differences IoT data protocols.

Radio Frequency Identification (RFID) and Wireless Sensors Networks (WSN) are technologies that their goal is to extend the functionality of ordinary objects and create a network of this objects with the purpose of generating valuable information.

For the final part of the chapter, publications of new technology that aims to help visual impaired people was presented. The publications are from research teams all over the worlds. These new inventions are based on the IoT that aims to create a portable device for helping blind people in their daily routine. This project collects all the successes and recommendations of these publications to create a useful device for the blind.

The next chapter talks about the different devices that forms part of the Blind Guide system, how these devices work and how they communicate between each other.

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3 Implemented Technologies

In the last chapter was presented the real situation for visually impaired in Ecuador and all over the world and how research teams are developing new technology based on the IoT. These solutions aim that blind can live better and be more active.

Blind Guide uses as foundations the knowledge acquired from the works of the research teams presented in the previous chapter. Blind Guide takes a step further. The system is portable solution, easy to use and to carry. It helps sightless people to navigate in unknown scenarios reducing the danger of a fall or an accident. The system performs well in outdoor or indoor scenarios. The system ensures that the user can use it at any time and in anywhere.

Blind Guide uses echolocation, the same ability that some animals have in order to capture their prey of travel in the dark without crashing. The system uses the small sensor that is distributed in the body of the user. There I two types of sensors in Blind Guide. One that has ultrasounds in order to find obstacles and a central sensor that gathers all the information of the ultrasounds for giving feedback to the user.

This new chapter lists all the electronic parts used in each device and the technologies implemented to make all the parts work together. The first part of this chapter talks about how each part of the system works and interact with each other. After that, the peripheral devices of the solution are presented and the technologies that are used in this sensor. Finally, we explain what is and how the main sensor of Blind Guide works.

3.1   Proposed Solution

The goal of the present project is to create a system that can be accessible for everyone. The electronic parts used in the Blind Guide prototype are easily obtainable using affordable off-the-shelf components available worldwide. The system is formed by two elements. The peripheral sensor that searches for obstacles in real time. Blind Guide can use the number of peripheral sensors as needed. These sensors can be attached to any part of the body. The recommended way is to use four sensors. One in the head, one in the chest and one in each leg. This configuration maximizes the obstacle detection. Different configurations can be used to work with another device like the white cane. In this case, only the sensors in the head and the chest, are needed to extend the range of action of the white cane.

The order part of the system is the central device. The central gathers the information sent wirelessly by the peripheral sensors. Process that information and if an obstacle is found uses a camera module to take a picture of the obstacle. The obstacle picture is sent to an image recognition cloud service. The service responds with the possible names of the obstacle. This information is transmitted to the user using a speaker.

3.2   Peripheral sensor

The primary function of the external sensor is to find nearby obstacles and alert wirelessly the central device. The sensor is formed by an ultrasound detector and a Wi-Fi microcontroller. Each external sensor has a 500 mA LiPo (Lithium Polymer) battery. A prototype of this sensor is illustrated in Figure 3.1.

Illustration 3.1 – Wi-Fi peripheral sensor.

The schematics for this device is in the next picture.
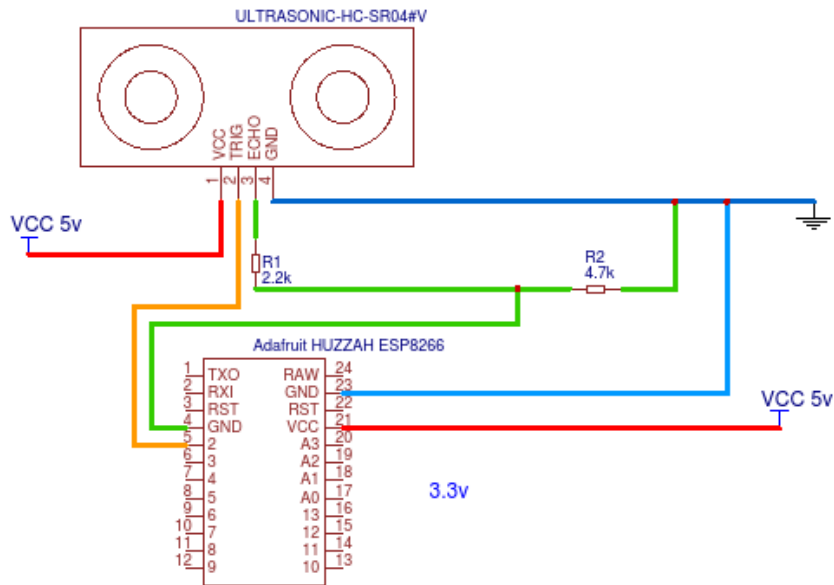
Illustration 3.2 – Wi-Fi peripheral schematics.

A variation of the peripheral sensor that uses Bluetooth Low Energy instead of using a Wi-Fi microcontroller is also implemented. Uses the same ultrasound and battery but this BLE sensor uses the HM-10 Bluetooth 4.0 for making the communication with the central device. Also, an Arduino nano module is used in order to process the data. A picture of this BLE peripheral devices is in the next picture.

Illustration 3.3 - BLE peripheral sensor.

The schematics for this device is in the following illustration.
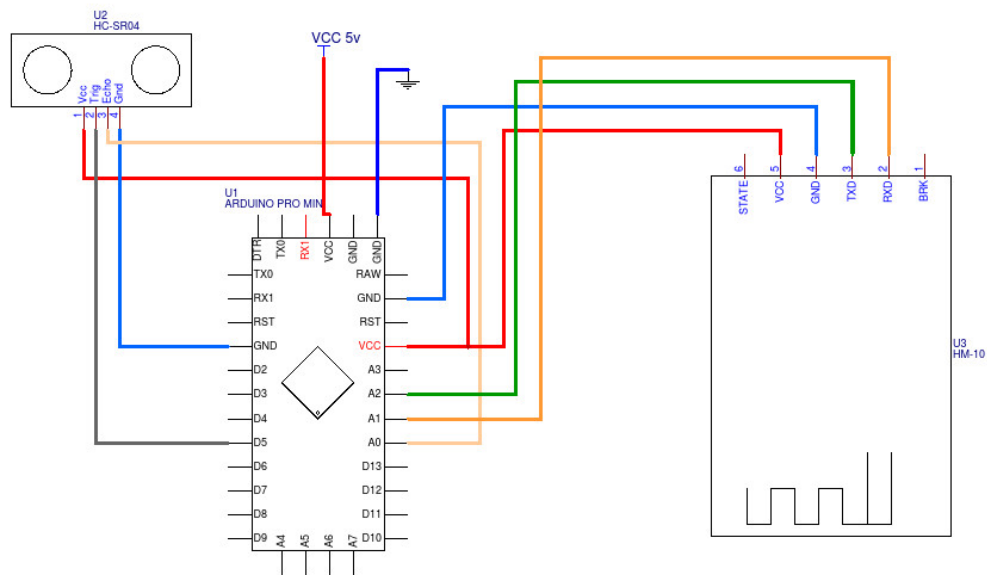
Illustration 3.4 - BLE peripheral schematics.

3.2.1 Ultrasonic sensor

For the purpose of detecting obstacles and ultrasonic sensor is used. The ultrasound transmitter emits a 40KHz ultrasonic wave that travels through the air and immediately returns if an obstacle is in the range of 2cm-400cm [12]. This effect is shown in the Illustration 3.2. The ultrasound system calculates the distance between the sensor and the obstacle and sends the data to the microcontroller. The sensor operates with a current of 15mA, and the cost of acquisition is very low [12].
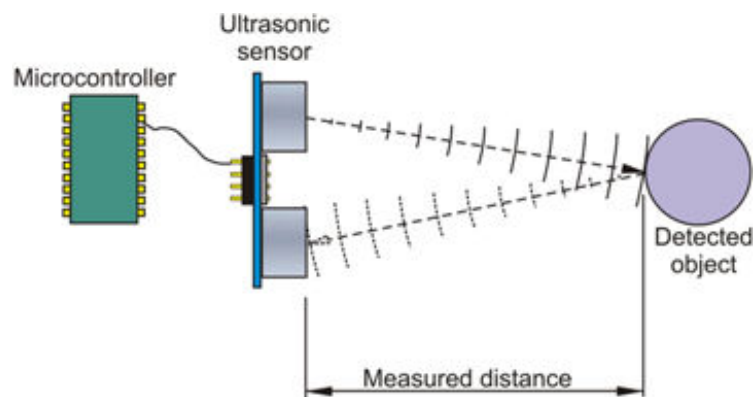
Illustration 3.5 - Ultrasound operation.

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3.2.2 Wi-Fi microcontroller

To send the information wirelessly if an obstacle is detected by the central a microcontroller with a Wi-Fi module was used. This microcontroller uses an 80 MHz ESP8266 processor with a Wi-Fi front-end that supports TCP/IP and DNS [13]. The microcontroller has a 3.3V out and a 500mA regulator [13].

The ultrasound sensor continuously sends data to the microcontroller. The microcontroller only alerts the central when the distance of the obstacle is less than the signal range configured in the microcontroller. The warning distance varies depending on which part of the body is placed the peripheral sensor. The reason for this configuration is because we want to limit the power consumption as much as possible.
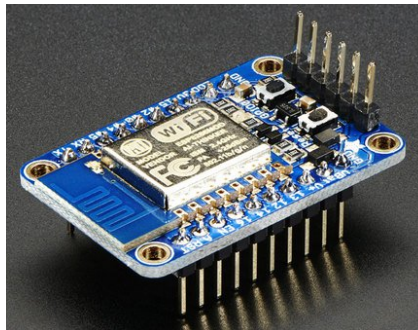
Illustration 3.6 - Wi-fi microcontroller.

3.2.3 Bluetooth Low Energy Module (HM-10)

The HM-10 is a 3.3v small Bluetooth low energy module based on the TI CC2540 or CC2541 from Texas Instruments. The HM-10 is developed by JNHuaMao Technology Company and is one of many Bluetooth devices the company produces. [32]

This HM-10 module works with +2.5v to +3.3v. Requires up to 50mA, uses around 9mA when is active and in sleep mode uses 50-200uA. HM-10 is compatible with Bluetooth 4.0. [32]

HM-10 has a group of services, and each service has a set of characteristics. The module works by setting the value of the custom characteristic to the value of the information to be transmitted. HM-10 then sends out a notification to the remote device to inform that new data is available. [32]

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Illustration 3.7 - HM-10 module. [32]

3.2.4 Peripheral Devices Power Consumption

Each type of peripheral device uses different technologies and the power consumption is different for each device. In the chart below is a comparison of each device power consumption.

Module	Wi-Fi peripheral	BLE peripheral
Ultrasound	~15mA	~15mA
Bluetooth low energy	-	~9mA
Wi-Fi module	~150mA	-
Arduino nano	-	~19mA
Battery	500mAh	500mAh
Consumption	165mAh	43mAh
Results	~3 hour of battery life	~12 hours of battery life

Illustration 3.8 - Peripherals battery consumption.

As illustrated in the previous table with a 500mAh LiPo battery the BLE peripheral has around twelve hours of batty life. In contrast, the battery life of the Wi-Fi peripheral reach only for three hours. As shown in previous chapters Wi-Fi technology consumes more battery rather than Bluetooth low energy. Wi-Fi also has advantages the range of the connection can reach up to 60 meters. BLE devices can only reach 15 meters. The requirements of the Blind Guide prototype is to have the peripheral devices attached to the body of the user for this reason BLE peripheral device is more suitable for goal of this project.

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3.3   Central device

The central device is the heart of the Blind Guide solution. It receives the information from the peripheral devices wirelessly. When an obstacle is encountered, takes a picture of the object. If the central has internet access, send the picture to an object recognition web service. The results and the distance of the obstacle are transmitted via speaker to the sightless person. The electronic parts that form the central device are a single-board computer, camera module, and a speaker. This device has a 2500 mA portable battery. With one single charge, the battery can last two days running for ten hours each day. The prototype of the central device is illustrated in Figure 3.4.
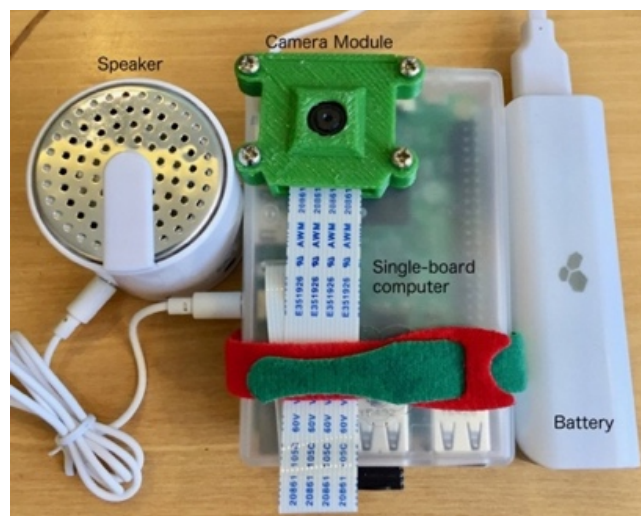
Illustration 3.9 - Central device.

3.3.1 Camera module

The central device has a camera module to take a picture of the obstacle when is detected by a peripheral device. This camera module has a Sony IMX219 8-megapixel sensor. The camera can take high definition videos or photos. Its supports 1080p30, 720p60 and VGA90 video modes [14]. The picture taken by the camera is sent to the cloud image recognition service. Bad quality photos can affect the recognition that is why a good quality camera is needed.
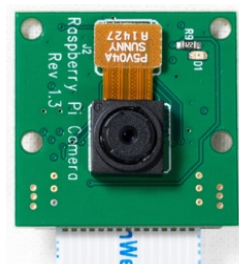
Illustration 3.10 - Camera module.

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3.3.2 Single-board computer

The central device needs a computer to process the messages from the peripheral devices and to communicate with the cloud image recognition service. The central device must be portable and fast as possible. We decided to use the credit card-size single-board computer called Raspberry Pi 3. This portable computer has a 1.2GHz 64-bit quad-core ARMv8 CPU, 802.11n wireless LAN, Bluetooth Low Energy (BLE) and 1GB RAM [15]. Raspberry Pi can be used with a variety of operating systems. For Blind Guide prototype, we choose Raspbian OS.

Raspbian OS is the most used operating system for Raspberry Pi and has a large community all over the world. This is a free operating system based on Debian which is optimized for the Raspberry Pi hardware.

Illustration 3.11 - Raspberry Pi 3.

3.3.3 Message Queue Telemetry Transport

To implement the communication between the Wi-Fi peripheral devices and the central device a low-power consume protocol was needed. Message Queue Telemetry Transport (MQTT) is an application layer protocol designed for resource-constrained devices [16]. This protocol depends on the Transmission Control Protocol (TCP) and IP. MQTT uses a topic-based publish-subscribe architecture [16]. This means that a client can send messages to an individual topic and all the clients subscribed to the same topic will receive the messages. The server that manages the communication is called the broker. In Blind Guide, the central device is the broker and also a client. The peripheral devices publish on the topic that the central device is subscribed to communicate.

Quality of Service (QoS) is implemented in MQTT in three levels [16]. Level 0 means that the message is delivered once and no acknowledgment is required. Level 1 is a confirmation that the message reception is required. Finally, level 2 implements a four-way handshake for the delivery of the message [16].
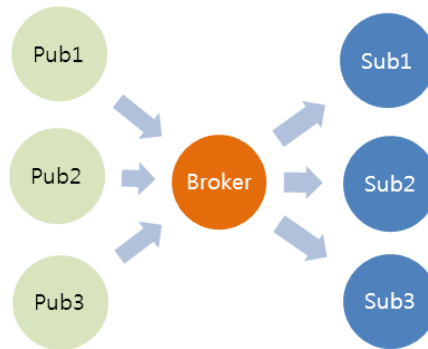
Illustration 3.12 - MQTT operation.

In the case of the BLE peripheral devices. Bluetooth low energy communication is used for exchange information form the central device to the peripheral devices. The communication uses the Connected Topology of BLE this means that each BLE peripheral device is connected to the central device forming a two ways communication channel.

3.3.4 Cloud Image Recognition Server

With Blind Guide, we try to give as much information as possible about the obstacles to the users. We choose to use an audible warning based on the results provided by a cloud image recognition service. The central device sends the photograph of the obstacle to the service using HTTPS (Hypertext Transfer Protocol Secure) protocol. The server responds a list in JSON (JavaScript Object Notation) format of possible things that the obstacle can be. The central device parses the information and chooses the top five possible options and transmits to the user by and audible warning.

We tested many image recognition services, and we decided to use a web service offered by the company Clarifai [17]. Clarifai provides an image recognition web service and many APIs for different programming languages. Our most important program that runs on the central device has been made using Python. Clarifai offers an easy to use Python API for accessing their services [17].

3.4 Synthesis

In this chapter contains a deeper description of each element used to produce the Blind Guide prototype. A brief description of the data flow of the prototype was presented. Blind Guide has two type of devices. Each type of device is meant to be portable, small as possible and has its battery. One of these devices is the peripheral sensor that is in charge of detecting obstacles and notifying the event wirelessly. The other gadget is called central and is in charge of receiving the notification from the peripheral sensors. When an alert is received uses its camera module to take a picture and sent it to an image recognition cloud service.

The first part of this chapter detailed the different parts that each type of peripheral sensor has. For the purpose of detecting incoming obstacles, this device has an ultrasound. This ultrasound uses echolocation to determinate if an obstacle is approaching and how far it is. A Wi-Fi microcontroller is used to process the information and to send a notification to the central device in the case of the Wi-Fi peripheral. In the case of the Bluetooth low energy peripheral an Arduino nano collects the information from the ultrasound and transmit the data to the central device using the HM-10 BLE module.

Each peripheral sensor has a Li-Po battery for making the ultrasound and the microcontroller work. The system can have as many as peripheral sensors needed. Each of the communicates directly with the central device forming a star topology. The communication in the Wi-Fi peripherals uses the Message Queue Telemetry Transport (MQTT) protocol. A protocol for resource constrained devices that improves energy consumption. In the case of the BLE peripherals the Connected Topology of BLE is used forming a two-ways channel between the peripheral device and the central device.

The next part of the chapter is about the central device. The core of the central device is a single-board computer that has a 1.2GHz 64-bit quad-core ARMv8 CPU, 802.11n wireless LAN, Bluetooth Low Energy (BLE) and 1GB RAM [15]. This device manages the connection with the peripheral sensors and processes the information that comes from that devices. When the central device receives the notification if an incoming obstacle uses its camera module to take a picture of the object. The picture is sent to an image recognition cloud service. This service responds with the possible names of the object. The central device chooses the five most probable names and transmits the information together with the distance. The information is sent via speaker to the user.

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The last part of this chapter talks about the protocol used for the communication between devices and the image recognition cloud service.

The MQTT protocol is optimized for devices with limited resources improving battery life of the devices. The use of this protocol causes that the topology for this prototype is the star topology. Each node communicates directly with a unique central sensor.

The main features of the proposed system called Blind Guide that we believe makes the system unique and helpful for sightless people are:

- Detects incoming obstacles using ultrasounds;
- The system is highly configurable (modular) can be used in different combinations. Adjusting to the user preferences and limitations;
- The system is scalable. A network of Blind Guide systems can store the localization of obstacles making it available for all users;
- Each sensor peripheral and central are small, portable and rechargeable;
- There is no need for cables because the communications between sensors are wireless;
- The system detects and recognize real world objects that other solutions cannot;
- The solution emits audible and real time warnings for the user;
- The warnings can be configured in the language preferred of the user;
- All the materials used in Blind Guide are low-cost making the prototype accessible for anyone;
- Blind Guide is an anytime and anywhere navigation solution for blind people.

For detecting incoming obstacles, an image recognition software is needed. This kind of programs consumes a lot of computational resources for making an accurate recognition. The central device has not enough computer power to make recognitions locally. That is why a cloud service is needed. This service must be fast, accurate and have compatibility with Python programming language.

In the next chapter, the process of investigation and the proposed architecture for the system is presented.

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4 System Design

Former chapter presented different technologies that the Blind Guide prototype uses. The prototype has two main elements the peripheral sensor and the central device. Chapter three given each item that conforms each device and how they work together to achieve the goals of this project. The peripheral device is in charge of detecting incoming obstacles. This device manages to identify objects using an ultrasound apparatus. The information from the ultrasound is processed and sent wirelessly to the central device by a Wi-Fi microcontroller. The central device gathers the information from the peripheral sensors and process it. When an obstacle is approaching, the central device takes a picture and sent it to the image recognition cloud service. The resulting information is transmitted in an audible warning to the visually impaired user.

Current chapter shows the investigation process used in this research to develop a viable prototype, based on the goals that were presented in previous chapters. The development process has many stages that are described below. The most important feature of the selected development process is the constant validation of the prototype with the final users. This feature helps to detect problems early in the process and correct them with the feedback from the users. The last iteration is a prototype that can be translated to production.

4.1   Investigation Process

With the purpose of explaining the steps of the investigation process is important to present some concepts. These ideas will help to explain the adopted research process and are listed below:

- Software prototyping;
- Functional requirements and non-functional requirements;
- Structured and unstructured interviews.

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4.1.1 Software Prototyping

The prototype is a model of the system to be developed that incorporates components of the actual product, this will be a representation of the scheme, although it is not a complete system. The prototype possesses the characteristics of the final system or part of them. A prototype has limited performance regarding capabilities, reliability or efficiency. [18]

The use of this method starts with the definition of the global objectives for the software and then move on to identify the known requirements and the areas of the scheme where more explanation is needed. Then, a prototype construction iteration is presented quickly, and the modeling is performed. [18]

With this rapid design, the prototype is evaluated by the client or the user. The evaluation results in feedback from the customer or user. The feedback makes possible to refine the requirements of the hardware/software that was developed. [18]

Iteration occurs when the prototype is adjusted to meet user needs. This allows the developer at the same time to better understand what needs to be done and the user to see results in the short term. The prototyping allows to deliver to the user what would be a vision the final solution in early stages of development, first reducing costs of erroneous specifications. [18] The phases of the software prototyping are listed below:

- **Preliminary investigation:** At this stage, the essential thing is to determine the problem, its scope, the importance and the potential effects that will have on the user. Identify a general idea of the solution to carry out a feasibility study; [18]

- **Verify the requirements:** The objective of this phase is to determine all the requirements and desires that the users have about the project that is wishing to implement. Here the developer interacts with the user and their needs through the construction, demonstration, and feedback of the prototype; [18]

- **Technical design:** In this stage, the developers determine the tools that are going to use, the materials, the user interface and the user experience; [18]

- **Create the prototype:** Implement the prototype based on the requirements and the guidelines of the technical design; [18]

- **Review and validate the prototype:** Test the prototype with the final users. The result is feedback from the users. Depending on the feedback the next step is to

adjust the prototype followed by another validation process or implement the final product; [18]

- **Apply the final product:** Transform the prototype in a product that can be deployed in the market.

Like all methodologies, software prototyping has advantages and disadvantages. The more important are listed below:

Advantages:

- Handy when the final user knows the general objectives of the product;
- There is a reduction of uncertainty and risk;
- Reduce time and costs;
- There is more communication between the developers and the user.

Disadvantages:

- It is not possible to use the methodology in all systems;
- Users can confuse the prototype with the final product. Generating mistrust.

4.1.2 Functional and Non-functional Requirements

Requirements are a condition that must be performed for the purpose of achieving an objective. Requirements can be divided in functional and non-functional. [19]

Functional requirements are the interaction between the system and the user or other external systems. These requirements are all the services that the system will offer. The non-functional requirements, on the other hand, are aspects not directly related to the functional behavior of the scheme. Non-functional requirements can be usability, rehabilitee, performance, supportability. [19]

4.1.3 Structured and Unstructured Interviews

In the moment of testing a prototype with the final users is important to get all the impressions of the volunteer about the prototype. Researchers can get feedback from the users using interviews. There are many types of interviews, which include: structured and unstructured interviews. [20]

The structured interview follows a series of fixed questions that have been prepared previously and the same questions apply to all interviewees. In the unstructured interview,

researchers work with open questions, without a pre-established order, acquiring the characteristics of conversation and allowing spontaneity. [20]

4.2   Proposed Architecture

Blind Guide is a solution for sightless people that alerts about incoming obstacles when the user is navigating in indoor or outdoor scenarios. The table 4.1 presents the functional and non-functional requirements for the project. These requirements are the base for designing the prototype. Each iteration of the prototype has a validation process in which the prototype is tested to verify if the requirement is satisfied. With each user test is possible that some requirements are added, changed or delete it.

N°	Requirement
1.	Each visually impaired will have a set of wireless peripheral sensors to detect incoming obstacles.
2.	The distance for alerting an approaching obstacle has to be customizable.
3.	The user will have the option of using the number of sensors that fit his/her needs.
4.	The system will have a central device that manages the information from the peripheral sensors. The central device will take a picture of the incoming obstacle for recognition and will alert the user using an audible warning.
5.	The audible alert must be in real time. The alert should not take more than a second after finding an obstacle.
6.	The audible alert includes the distance of the user to the obstacle and five possible names of the object.
7.	The system must be portable, easy to wear and visually impaired friendly.
8.	All the materials that Blind Guide requires must be easy to find and affordable.

Table 4.1 - Functional and non-functional requirements.

The system works in the following way: Blind Guide is composed of two elements. One is the peripheral sensor that has an ultrasound and a Wi-Fi module. The ultrasound uses ultrasonic waves to detect an obstacle. The range of action of the ultrasound is 2cm to 400cm.

The Wi-Fi module has an ESP8266 processor with a Wi-Fi front-end. The ESP8266 processor contains the logic that monitors the ultrasound and the communication with the central device. The Wi-Fi module logic is in the Appendix A. In the BLE peripheral

devices an Arduino nano microcontroller contains the logic that monitors the ultrasound and the communication via BLE to the central device.

Blind Guide can use many peripheral sensors as needed. We suggest four peripheral sensors: one for the forehead, one in the chest and two in each leg. A simulation of the prototype working is shown in the Illustration 4.1.

Illustration 4.1 - Blind Guide simulation.

The second is the central device that is composed of a single-board computer, a camera module, and a speaker. Blind Guide just needs one central device that should be placed in the chest. The single-board computer is a Raspberry Pi version 3 which includes a Wi-Fi and Bluetooth adapters. The operating system of the Raspberry Pi 3 is a called Raspbian which is based in Debian operating system.

The communication between the Wi-Fi peripherals and the central device is via Wi-Fi using the MQTT protocol. This distribution forms a star topology. In the case of the BLE peripheral devices the communication is using Bluetooth low energy standard and also forms a star topology.

When an obstacle is detected the peripheral sensor alerts the central appliance. Then the central device takes a picture of the obstacle using the camera module. The picture is uploaded to the cloud image recognition service. When the server responds, the result is transformed into an audible warning. This logic was programmed using Python language. Python does not require any configuration on Raspbian, has a great support and provides all the necessary libraries for developing the interaction between the different components

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of Blind Guide. The python program is in the Annexed A. The Illustration 4.2 shows the interaction between the components of the prototype.
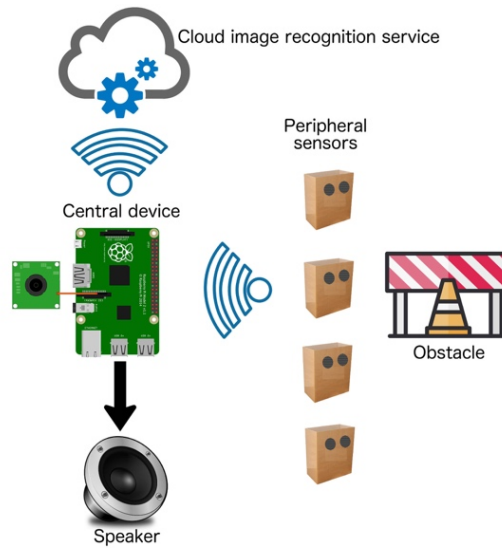
Illustration 4.2 - Components interaction.

The information flow of the system works in the following way. All start in the peripheral sensor. The Wi-Fi microcontroller parses the information from the ultrasound sensor to know if an obstacle has been found. If an obstacle appears, the peripheral sensor sends a warning to the central device. Then the central device takes a picture. If there is internet access the device uploads it to the cloud image recognition service. After that, the central device waits for the server response. When the cloud service sends the result, the central device parses the information. The resulting data is transformed into an audio file, which is transmitted to the speaker. The Illustration 4.3 clarify the information flow.

Illustration 4.3 - Information flow.

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4.3   Synthesis

The first half of the actual chapter showed us the investigation process used in this research and how choosing the right methodology can improve the development. The method selected for this project is Software Prototyping. Even though the preferred method is mainly for software development, the process adjusts the requirements of this project. Is based on an iterative methodology. The main idea is to quickly develop a prototype and test it 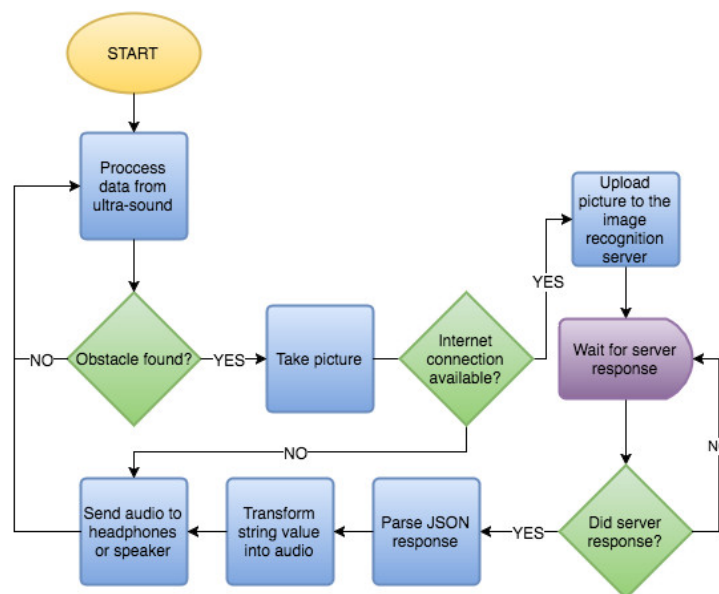with the final users. This test results in feedback. This feedback is the verification if an individual requirement is satisfied. If there are any improvements to make a new iteration is made. If the prototype satisfies all the requirements, it can be moved to production.

The other half of the chapter show us the requirements imposed on this project. The architecture chosen for satisfying the project requirements is explained in detail. The logic in every step of the information flow is shown. How the information travels from detecting an obstacle to alerting the user.

The use of this architecture ensures that each peripheral sensor has a direct link of communication with the central device. This direct link certifies that if a peripheral device detects and obstacle the central device will be informed as soon as possible. This configuration makes the system work in real time. Quick response times are vital for systems like the proposed one. Any delay to inform the user of an incoming obstacle can cause an accident that will destroy the trust of the user in the system.

The proposed architecture makes Blind Guide a modular system. The system can be used with one peripheral sensor up to the number needed for the users. Modularity enables the system that can be used at the same time with other solutions.

Blind Guide is able to send information to a network. This network stores the geographic coordinates and the description of obstacles found by the Blind Guide systems. This information is available for all systems. This information is vital for make a quick alert to the user, preventing accidents.

In chapter five, the results of the test performed on the system with sightless volunteers is presented. The feedback from the volunteers allow us know if the proposed solution is useful for blind people.

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5 Evaluation

Former chapter was about the methodology selected for developing Blind Guide prototype and how this procedure provides a controlled process for development. The chosen method is Software Prototyping. Even thought is for software development; this methodology adjusts the needs of the project. Chapter four also contains the functional and non-functional requirements for this project. The requirements are continually being validated with the final users. Each iteration of the prototype has feedback from the user improving the next iteration. Based on the needs the architecture of Blind Guide was design and presented in chapter four and showing how the different parts of the model design work and how they interact with each other.

The current chapter contains how the final iteration of the prototype was tested. The first part describes how the evaluation was carried out. Describing the assessment step by step and the characteristics of the volunteers for the trials. At the end of the chapter, we present the interviews of the volunteers with the feedback of Blind Guide.

5.1 Evaluation process

To know if the Blind Guide solution can help visually impaired in their daily lives test where performed. We check the prototype with five blind people of different ages. The participants were informed about the objective of the experiments and instructed about how the prototype works. All the volunteers gave consent regarding the publication of photos and other information related to the investigation. The process of introduction of the system was the following: First, we explain to the volunteers how the prototype of the scheme works. We let the volunteers touch and explore the peripheral sensors, the central device, and the straps to make them get used to the different parts. Finally, we explain to them how to wear the system and let the volunteers do it by themselves. We did not give them physical help in this process because we wanted to know if the system can easily

wear it by a blind person without any help. This first test was a success. With a little explanation, the volunteers were able to attach the prototype in their body.

Next, we perform a test in indoors and outdoors. For this test, two different set ups of the system were used: One was using only two peripheral sensors, one in the head and the other in the chest. The other configuration was using four sensors, one in the head, one in the chest and two in each leg. Both configurations used the central device.

For the purpose of giving the audible warnings, the central device has a standard headphone jack. In this headphone jack, we can attach regular headphones or a mini speaker. The use of each one depends on of the preference of the blind person using the system. In our research, we identify that some visually impaired does not like to use headphones because they developed their sense of hearing and they see using this sense. On the other hand, others like to use headphones but not in a regular way. This group likes to put the headphone close to their ear. With the utilization of a regular headphone jack, we assure that the system can adjust to the user preference.

Illustration 5.1 shows a picture of volunteers trying our prototype. The left volunteer is the president of the PROCODIS foundation. An organization with the goal of teaching about disabilities using standard communication media. The right photograph shows a student of the Mariana de Jesús Foundation. It is a school for visually impaired children.

Illustration 5.1 – Volunteer from Procodis trying Blind Guide prototype.

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Illustration 5.2 - Explaining how the prototypes works to the volunteers.

Illustration 5.3 - Student of the Mariana de Jesús Foundation.

Our tests indicate that our prototype requires at most fifteen minute practices to understand how it works. In the indoor evaluation, we examine the system identifying chairs, tables, doors, walls and ordinary objects inside an office. We test walking on the sidewalk, crossing the street and avoiding common objects in the road like light posts or trash cans in the outdoor evaluation. The system performs as expected in both scenarios. Each peripheral sensor works in the same way, but our volunteers hint that the most valuable of all is the one that is placed in the head. The reason of this is because there is not a device on the market that can help them to avoid high obstacles. That can hit them in the head such as branches.

After the tests, we received feedback from the volunteers. First, the distance for detecting an obstacle must be between two and two and a half meters. During the tests, the prototype was using a one-meter range for detecting obstacles. By the time the prototype gave the audible warning while the user was walking the user already hit the obstacle. Second, for the audible alert, a human voice must be use. The voice of our prototype was like a robot and was not pleasant to their ears. Finally, the peripheral sensors and central must be small as possible. The sensors of our system are not comfortable to wear, and they need straps to attach to the body.

5.2   Interviews

Interviews were conducted for the purpose of validating the prototype and verify if the requirements imposed for this project were satisfied. The feedback obtained from this interview help us to understand if the system is useful for visually impaired or we have to change the requirements of the system. Three interviews were conducted with volunteers after they tested the prototype.

5.2.1 Interview with Walker Verdesoto – Procodis Foundation

Walker Verdesoto is the CEO of the Procodis foundation. Procodis is a non-governmental organization that promotes participatory social communicators. Their team train children, adolescents, seniors with total blindness and low vision.

Walker Verdesoto lost vision in his adulthood, and he knows the challenges that people that lost vision have to overcome. He performs a rehabilitation process to people that lost sight. The goal of rehabilitation is for people to gain their trust again.

Walker test Blind Guide prototype in the street. Using four peripheral sensors, one in his head, one in his chest and one in each leg. After the test, we perform an unstructured interview.

Walker told us that our system without any modification could help with the process of recovery. This is because our system requires wear it on. This activity helps blind people in their motor skills. When a person became blind, they need to improve their motor skills to compensate their missing sense. Also, our prototype can help sightless to overcome downhearted. When a blind person learns how to use some technology for blind people, they rejoice. This is because they realize that they can still have a healthy life.

5.2.2 Interview with Mario Puruncajas – FENCE

Mario Puruncajas is blind and the president of the National Federation of the Blind of Ecuador (Fence). Fence is a non-profit legal organization created to serve the visually impaired in Ecuador. Its main purpose is to promote the progress and development of the blind following the modern trends of typology and ensure the cultural, educational, economic and social improvement of its institutions and associated persons.

The Blind Guide prototype was presented to Mario. Using his hands explore the system and of part of it while the interviewer was telling him about how the prototype works. After the introduction, the interviewer started an unstructured interview.

Mario told the interviewer that one of the many problems that suffer a blind person is being injured in the head. The white cane helps a blind person to navigate in indoors and outdoors scenarios and protect them from falling or crashing. But the white cane only offers protection below the waist level. Mario believes that is an important feature that Blind Guide can work altogether with other solutions like the white cane. Mario recommends that the peripheral and the central devices must be small as possible. The reason of this is seeking the user comfort. Another recommendation is to add facial recognition to the system. This helps visually impaired to know how is front of them. As a final statement, Mario told the interviewer that any effort to help blind people having a normal life is valuable.

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5.2.3 Interview with Silvia Crespo – Instituto Mariana de Jésus

Silvia Crespo is the director of the Mariana de Jésus Institute. This Institute is a school for children with multiple disabilities and offers others services like early stimulation, visual rehabilitation, among others.

Silvia allows us to test the Blind Guide with a group of six children of different age and different degree of visual impairment. First, the interviewer explains the group of children what the system does and how it works. Then the children explore the peripheral and the central devices using their hands. Then each child starts testing the system in the school playground.

After the trial phase, we interview the children and Silvia Crespo about the prototype. Like in previous interviews, the recommendation of making the devices small as possible was given. Silvia told us that blind people is vain as ordinary people and they don't like to wear things that make them look ridicule even if that thing improves their quality of life. They told us that the voice of the audible alert was speaking to slow and should include a more precise description of the obstacles. In general, they think that the device is useful and can help blind people to avoid injuries.

5.3 Synthesis

This chapter showed the process used to evaluate the Blind Guide prototype with visually impaired volunteers. The methodology employed to introduce the system to the volunteers and the tests in real life environments.

The first part of the chapter explained the process of the evaluation. First, the interviewer explained to the volunteers how the system works and what is the purpose of each element of the scheme. Then the volunteers explored each device with their hands. Any question from the volunteers was answered by the interviewer. Then with the help of the interviewer, the system was attached to the volunteer. When the system was ready, the volunteer started to walk around. The interviewer was watchful of the volunteers seeing how this one reacts with the feedback of the prototype. In the end, the interviewer collected all the feedback from the evaluation.

The second part of the chapter has an abstract of the interviews of the most important volunteers that tried our system. As one of the frequent requests from the volunteers was that the device most is small as possible. The person that uses the system must not feel silly

wearing Blind Guide. Also, a requested feature was face recognition. This feature can help the user to identify the people that are around them increasing safety. The prototype was well received, and one unexpected result was found. This came from a professional of impaired visual rehabilitation. This person told us that the prototype could be used for gaining confidence.

The trials performed to Blind Guide show us positive results. The system successfully detected incoming obstacles and informed in real time to its users. The volunteers gave us a positive feedback telling that they felt comfortable using the prototype and they believe that the system can help them with their daily routine, but more extensive use of the prototype will confirm this.

The volunteers compared the experience using Blind Guide with other devices and they told us that Blind Guide is the first device for blind people that recognize obstacles. This information is vital for them because knowing what obstacle is approaching them help them to choose the best way to avoid crashing with the obstacle.

In the next chapter with present the final conclusions of the Blind Guide system and the future plans for the prototype.

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6 Conclusions and Future Work

This work presents the development and description of Blind Guide. Blind Guide is a navigation system for sightless people in outdoors or indoor scenarios. This system detects and calculates the distance of an incoming obstacles that the user is approaching to it, using an ultrasound.

The sensor that uses the ultrasound is called peripheral sensor and can be attached to any part of the body of the user. The peripheral sensor sends a wireless signal to the central device when an obstacle is detected. The star topology used in this system allows it to have has many peripheral sensors as needed and each of these sensors has a direct wireless link of communication with the central device.

When an obstacle is detected the system takes a picture using a camera module. The picture of the object is uploaded to an image recognition web service. This web service responds with the predictions of the name of the object. The system takes the top five predictions and alerts the user using a speaker. The alert is audible and contains the name of the sensor that detected the obstacle (head, chest, legs), the distance of the object and the possible names. This process is performed in the central device.

The principal objectives of this work are the development of a system that helps blind people to walk in outdoors and indoors scenarios. The solution must be accessible for anyone. This goal is achieved making the device low-cost and the materials have to be available in any part of the world. The system has to work in real-time, the time between the detection of an obstacle and the firing of the alert to the user must be at least 0.5 seconds or less. The device must be portable, rechargeable and comfortable to use. This makes the system an anytime and anywhere solution.

In chapter two, a study of the scientific knowledge in the area of the IoT was carried out, in which this work is based. It was intended to make known the challenges and possible solutions and trends. Also contains statistics about the reality of visually impaired in the world and Ecuador. There is around 285 million of the blind, most of them are aged above fifty and live in low-income settings. Chapter two also contains the concept of IoT and the technologies on which it is based and relies on. The description of Wi-Fi, Wi-Fi Direct, Bluetooth Low Energy and how these technologies help in the communication device to device, an essential part of IoT. The differences of Wi-Fi Direct and Bluetooth Low Energy was described. Each technology has their advantages and disadvantages, and the main reason for choose one or another is the requirements for the project.

Chapter three contains a deeper description of each element used to produce the Blind Guide system. A brief description of the data flow of the prototype was presented in that chapter. Blind Guide has two type of devices. Each type of device is meant to be portable, small as possible and has its battery. One of these devices is the peripheral sensor that is in charge of detecting obstacles and notifying the event wirelessly. The other gadget is called central and is in charge of receiving the notification from the peripheral sensors. When an alert is received uses its camera module to take a picture and sent it to an image recognition cloud service. In chapter three we talk about the MQTT protocol that is optimized for devices with limited resources improving battery life of the devices. The use of this protocol causes that the topology for this prototype is the star topology. Each node communicates directly with a unique central sensor.

The chapter four showed us the investigation process used in this research and how choosing the right methodology can improve the development. The method selected for this project is Software Prototyping. The main idea of this method is to quickly develop a prototype and test it with the final users, resulting in feedback. Feedback is the verification if an individual requirement is satisfied. If the prototype satisfies all the requirements, it can be moved to production.

The architecture chosen for satisfying the project requirements is explained in detail in chapter four. The logic in every step of the information flow is shown. How the information travels from detecting an obstacle to alerting the user. The selected architecture ensures that each peripheral sensor has a direct link of communication with the central device. Any delay to inform the user of an incoming obstacle can cause an accident that will destroy the trust of the user in the system.

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Finally, the trials performed to Blind Guide show us positive results. The system successfully detected incoming obstacles and informed in real time to its users. The volunteers gave us a positive feedback telling that they felt comfortable using the prototype. The volunteers told us that the most important feature of Blind Guide is its ability to identify obstacles. This feedback is useful for them because knowing what obstacle is approaching them help them to choose the best way to avoid crashing with the obstacle.

6.1 Main Contributions

As a result, the main contributions of this work are the investigation of the reality of blind people around the world. The research in existing technologies for helping sightless people. Investigation in technologies for wireless communication in the IoT field. The design of an architecture for a low-cost system that helps blind people navigate preventing accidents. This architecture enables anytime and anywhere characteristics in the system. Finally, the implementation of the Blind Guide solution and the test results in sightless volunteers.

In our investigation, we found that there is around 285 million of the blind, most of them are aged above fifty and live in low-income settings. This first part contains the most common diseases that cause visual impairment, some of them are treatable but for lack of resources, people don't have access to medical resources. We explore the concept of IoT and the technologies on which it is based and relies on. Describing Wi-Fi, Wi-Fi Direct, BLE and how these technologies help in the communication device to device, an essential part of IoT. Each technology has their advantages and disadvantages, and the main reason for choose one or another is the requirements for the project. In our case, we experiment with both technologies and BLE adjust more for our requirements because of its low power consumption. Making the solution low-cost was another important requirement. As presented earlier the people that need the most the solution lives in low-income settings.

The topology chosen for the architecture of Blind Guide is the star topology. This topology used in the system allowing it to have has many peripheral sensors as needed and each of these sensors has a wireless direct link of communication with the central device. A fast communication between peripheral and central devices are primordial for this solution. When an obstacle is detected must be identified and the user must be informed as soon as possible preventing an accident.

None of the existing solutions for sightless has a network fed by the users of the system. The information stored in the network is available for all the systems making the object detection faster and reliable. As the users of the network grow, the amount of useful information stored in the network increases.

As a summary, the investigation process, the chosen architecture and the test in real world gave us the certainty that the proposed solution achieves the goals imposed by this system. Blind Guide is a valid solution for helping the sightless to navigate in unknown scenarios. Blind Guide meets this goal being an anytime, anywhere and low-cost system.

6.2   Future Work

We have developed a blind guide for helping sightless to navigate in indoor and outdoor scenarios. We have tested the blind guide prototype with visually impaired and we had satisfactory results. Using this system, the users can identify and avoid obstacles in real life scenarios, which is very helpful especially in unknown situations. With the materials employed in this prototype, we can assure that this is a low-cost solution for visually impaired.

Our prototype requires a local network for internet access to perform the object recognition. In the future, with the addition of a 4G, 3G or GSM module for the central device can allow the system have internet access at all time. Another feature that can be added to the system is to perform image labeling in the central device. This feature is possible using machine learning libraries. These libraries give us the possibility to feed a neural network with pictures of common obstacles that a blind person might encounter. The labeling will be performed in the central device without using internet access.

The results of our test we found that our system also can be used in the rehabilitation of people that recently became blind. In the future, we want to create to systems. One for rehabilitation and the other for daily use in indoors and outdoors scenarios.

We want also test new forms that the system can give feedback to the users. This prototype only provides audible warnings to the users. Haptic feedback can be more discrete and comfortable for some scenarios.

The system also needs an improvement regarding charging the devices. Must be easy for anyone to charge them.

We also want to increase the number of cameras that the system use, with the purpose of improving the effectiveness of the detection of the obstacles and environment mapping. The camera takes good pictures for the recognition only with good light conditions. For the future, we want to try different cameras to solve the light problem.

Enabling the system giving a description of the environment where the user is can enhance the process of cognitive mapping of the environment. Giving the user more confidence on exploring new areas. We believe that a good feature can be face recognition, to help the users interacting with others.

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8 Appendices

Appendix A – Peripheral sensor logic

```
1.   #include <ESP8266WiFi.h>
2.   #include <PubSubClient.h>
3.   #include <elapsedMillis.h>
4.   #include "ESP8266TrueRandom.h"
5.
6.   char sensorUUID[40];
7.   const char* sensor_name = "cabeza";
8.
9.   // Wifi
10.  const char* ssid = "Pi3-AP2";
11.  const char* mqtt_server = "172.20.0.1";
12.  WiFiClient espClient;
13.  PubSubClient client(espClient);
14.  char msg[50];
15.
16.  // MQTT Topics
17.  char* newClient  = "newClient";
18.  char* outTopic = "outTopic";
19.
20.  //Ultrasonic sensor HC-SR04
21.  const byte trigPin = 5; //4;    // Trigger pin is on GPIO4
22.  const byte echoPin = 4; //16;   // Echo pin is on GPIO16
23.  int triggerDistance = 0;   // Distance to notify the server
24.
25.  elapsedMillis lastServerCallTimeElapsed; // Last call to the server
26.  unsigned int serverCallInterval = 5000;  // Minimum time to call the server again
27.  bool objectClose = false;
28.
29.  void setup() {
30.    pinMode(BUILTIN_LED, OUTPUT); // Initialize the BUILTIN_LED pin as an output
31.    pinMode(trigPin, OUTPUT); //Initialise input/output pins
32.    pinMode(echoPin, INPUT);
33.    Serial.begin(115200);
34.    // Generate a new UUID
35.    byte uuidNumber[16];
36.    ESP8266TrueRandom.uuid(uuidNumber);
37.    String UUID = ESP8266TrueRandom.uuidToString(uuidNumber);
38.    UUID.toCharArray(sensorUUID, 40);
39.    Serial.print("The UUID number is ");
40.    Serial.println(sensorUUID);
41.    setup_wifi();
42.    client.setServer(mqtt_server, 1883);
43.    client.setCallback(callback);
44.  }
45.
```

63

```
46.  void setup_wifi() {
47.    delay(10);
48.    Serial.println();
49.    Serial.print("Connecting to ");
50.    Serial.println(ssid);
51.    WiFi.begin(ssid, "");
52.    while (WiFi.status() != WL_CONNECTED) {
53.      delay(500);
54.      Serial.print(".");
55.    }
56.    Serial.println("");
57.    Serial.println("WiFi connected");
58.    Serial.println("IP address: ");
59.    Serial.println(WiFi.localIP());
60.  }
61.
62.  void callback(char* topic, byte* payload, unsigned int length) {
63.    Serial.print("Message arrived [");
64.    Serial.print(topic);
65.    Serial.print("] ");
66.    if (strcmp (topic,sensorUUID) != 0) {
67.      Serial.println("Message no processed !!");
68.      return;
69.    }
70.    char message[length];
71.    for (int i = 0; i < length; i++) {
72.      message[i] = (char)payload[i];
73.    }
74.    message[length] = '\0';
75.    Serial.println(message);
76.    triggerDistance = atoi(message);
77.    Serial.println(triggerDistance);
78.  }
79.
80.  void reconnect() {
81.    while (!client.connected()) { // Loop until we're reconnected
82.      Serial.print("Attempting MQTT connection...");
83.      if (client.connect(sensorUUID)) { // Attempt to connect
84.        Serial.println("connected");
85.        client.subscribe(sensorUUID);
86.        if (triggerDistance <= 0) {
87.          snprintf (msg, sizeof(sensorUUID), sensorUUID);
88.          client.publish(newClient, msg);
89.        }
90.      } else {
91.        Serial.print("failed, rc=");
92.        Serial.print(client.state());
93.        Serial.println(" try again in 5 seconds");
94.        // Wait 5 seconds before retrying
95.        delay(5000);
96.      }
97.    }
98.  }
99.
100. void print_distance (int distance) {
101.   Serial.print("Distance: ");
102.   Serial.print(distance);
103.   Serial.println(" cm");
104. }
105.
106. void loop() {
107.   if (!client.connected()) {
108.     reconnect();
109.   }
110.   client.loop();
111.   long distance = distanceData();
```

```
112.    if (triggerDistance <= 0) {
113.       Serial.println("Max distance not set. !!!");
114.       return;
115.    }
116.
117.    if (distance > 0 && distance < triggerDistance) {
118.       if (!objectClose && lastServerCallTimeElapsed > serverCallInterval) {
119.          snprintf (msg, sizeof(sensorUUID) + 16, "%s*%ld*%s", sensorUUID, distance, sen
     sor_name);
120.          Serial.print("Publish message: ");
121.          Serial.println(msg);
122.          client.publish(outTopic, msg);
123.          objectClose = true;
124.          lastServerCallTimeElapsed = 0;
125.       } else {
126.          print_distance (distance);
127.       }
128.    } else {
129.       if (objectClose) {
130.          objectClose = false;
131.       }
132.       print_distance (distance);
133.    }
134.    delay(500);
135. }
136.
137. long distanceData() {
138.    long duration, distance;
139.    digitalWrite(trigPin, LOW); // send the pulse
140.    delayMicroseconds(2); // low for 2 microseconds
141.    digitalWrite(trigPin, HIGH);
142.    delayMicroseconds(10); // high for 10 microseconds
143.    digitalWrite(trigPin, LOW);
144.    duration = pulseIn(echoPin, HIGH); // measure the time to the echo
145.    distance = int(0.017*duration); // cm
146.    return distance;
147. }
```

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Appendix B – Central Device Logic

```python
1.  import paho.mqtt.client as mqtt
2.  from bg_photoManager import PhotoManager
3.  from bg_clarifaiService import ClarifaiService
4.  from sys import platform
5.  from bg_utility import Utility
6.
7.  sensor_distance = 90
8.
9.  def on_connect(client, userdata, rc):
10.     print("Connected with result code " + str(rc))
11.     client.subscribe(activeClients)
12.     client.subscribe(msgFromSensor)
13.     client.subscribe(newClient)
14.
15. def on_message(client, userdata, msg):
16.     payload = msg.payload.decode('utf-8')
17.     if msg.topic == newClient:
18.         print(msg.topic + " " + payload)
19.         new_sensor(payload)
20.
21.     if msg.topic == activeClients:
22.         print(msg.topic + " " + payload)
23.
24.     if msg.topic == msgFromSensor:
25.         print(msg.topic + " " + payload)
26.         recognition_process()
27.
28.         # Say distance and name of the sensor
29.         payload_array = payload.split('*')
30.         Utility.device_speak([Utility.cm_to_step(int(payload_array[1]), payload_array
    [2])])
31.
32. def new_sensor(sensor_id):
33.     print('Publish ' + sensor_id)
34.     client_mqtt.publish(sensor_id, str(sensor_distance))
35.
36. # async def recognition_process():
37. def recognition_process():
38.     photo_taken = PhotoManager.take_picture()
39.     if len(photo_taken) > 0:
40.         print(ClarifaiService.recognize_image(photo_taken))
41.
42. PhotoManager = PhotoManager()
43. ClarifaiService = ClarifaiService()
44. MqttServer = "localhost"
45.
46. if platform == "darwin":
47.     MqttServer = "192.168.0.9"
48.
49. newClient = "newClient"
50. activeClients = "$SYS/broker/clients/active"
51. msgFromSensor = "outTopic"
52.
53. client_mqtt = mqtt.Client()
54. client_mqtt.on_connect = on_connect
55. client_mqtt.on_message = on_message
56.
57. client_mqtt.connect(MqttServer, 1883, 60)
58.
59. try:
60.     client_mqtt.loop_forever()
61. finally:
```

```
62.    print("BYE !!")
63.    client_mqtt.disconnect()
64.    client_mqtt.loop_stop()
```