Real-time bicycle management system

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Thesis to obtain the Master of Science Degree in

Electronics Engineering

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December 2020

Declaration:

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Abstract

With the urban mobility paradigm changing, with the development of different kinds of vehicles and different technologies, there is the need to adapt and evolve with different solution. In this work the focus is in one of the most used vehicles around the world, considered as the cleanest but sometimes underestimated, the bicycle. This vehicle is used daily by millions of people around the world, for different purposes. Although the possibility to ride in the road as a motorized vehicles, there are plenty of differences that make the riders vulnerable.

The goal is to transform the bicycle into an intelligent and complete vehicle in order to increase the user safety and comfort and at the same time encourage others to use it. In order to achieve it,it was developed a safety system that gives more information to the rider from the rear angles. The system is composed by a device that is mounted under the bicycle's seat and a user-interface application running on a smartphone that is fixed in the handlebar.

Keywords

Urban Mobility, Road Safety, Bicycle, Embedded System, Sensors.

Resumo

Com a mudança do paradigma da mobilidade urbana, com o desenvolvimento de diferentes tipos de veículos e diferentes tecnologias, surge a necessidade de adaptação e evolução com diferentes soluções. O foco deste trabalho é num dos veículos mais usados em todo o mundo, considerado o mais ecológico mas por vezes subestimado, a bicicleta. Este veículo é utilizado diariamente por milhões de pessoas em todo o mundo, para diversos fins. Apesar da possibilidade de andar na via publica como um veículo motorizado, existem muitas diferenças que tornam os ciclistas mais vulneráveis.

O objetivo deste trabalho é transformar a bicicleta num veículo inteligente e completo, a fim de aumentar a segurança e o conforto do ciclista e ao mesmo tempo incentivar outras pessoas a usá-la. Para isso, foi desenvolvido um sistema de segurança que dá mais informações ao ciclista sobre os ângulos traseiros, como a distância a veículos e a imagem em tempo real. O sistema é composto por um dispositivo que é montado debaixo do acento da bicicleta e uma aplicação que faz a interface com o ciclista, através do seu smartphone colocado no guiador da bicicleta.

Palavras Chave

Mobilidade Urbana, Segurança, Bicicleta, Sistema Embebido, Sensores.

Contents

List of Figures

Acronyms

ACL Asynchronous Connection-Less

ATT Attribute Protocol

BLE Bluetooth Low Energy

BSS Basic Service Set

BT Bluetooth

CAD Computer Aided Design

CPU Central Process Unit

CMOS Complementary Metal Oxide Semiconductor

CSI Camera Serial Interface

DPSK Differential Phase Shift Keying

DQPSK Differential Quadrature Phase Shift Keying

EDR Enhanced Data Rate

FPGA Field Programmable Gate Arrays

GAP Generic Access Profile

GATT Generic Attribute protocol

GFSK Gaussian Frequency Shift Keying

GPIO General Purpose Input/Output

GPS Global Positioning System

GPU Graphics Processing Unit

GSM	Global System for Mobile communications
HCI	Host Controller Interface
HTTP	Hypertext Transfer Protocol
I2C	Inter-Integrated Circuit
IC	Integrated Circuit
IoT	Internet of Things
IP	Internet Protocol
IR	Infra-Red
ISM	Industrial Scientific Medical
LED	Light Emitting Diode
L2CAP	Logical Link Control an Adaptation Protocol
LIDAR	LIght Detection And Ranging
LTE	Long Term Evolution
MAC	Medium Access Control
MISO	Master In Slave Out
MOSI	Master Out Slave In
MPE	Maximum Permissible Exposure
OS	Operating System
PCB	Printed Circuit Board
QoS	Quality of Service
RADAR	RAdio Detection And Ranging
RAM	Random-access memory
RF	Radio Frequency
RFCOMM	Radio Frequency Communication
RPi	Raspberry Pi

RTOS	Real-Time Operating System
SMP	Security Manager Protocol
SCO	Synchronous Connection Oriented
SCK	Serial Clock
SOC	System-on-Chip
SPI	Serial Peripheral Interface
SS	Slave Select
TCP	Transmission Control Protocol
TOF	Time-Of-Flight
UART	Universal Asynchronous Receiver/Transmitter
US	Ultra Sound
USB	Universal Serial Bus
VMS	Variable Message Sign
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area network

1

Introduction

Contents

Introduction

1.1 Purpose and motivation

The mobility paradigm is changing everyday, with different kinds of vehicles, with different intelligent transport systems technologies [1], and the need of adapting and evolving is a constant. The world is changing and clean ways of travelling are a priority to a part of the scientific community, engineers and developers all over the world.

Although there are some countries and cities where the bicycle takes an important role, in Portugal the scenario is slightly different, as it was possible to see in the study [2] in Agueda. In this study it was possible to conclude that the main barriers for the students not cycle to school is the risk of accidents with other vehicles and the presence of hilly streets. Other reasons that motivate these difficulties are related to the absence of unique infrastructures and lanes for bicycles. This difficulty might be hard to overcome, because investments in infrastructures sometimes are not possible, not only for monetary reasons but also for geographical and space ones.

Bicycle sharing systems [3] like the one described in [4], that counts with more than one million trips annually, are being installed in some major cities in the world. These systems offers a service that allow people that can not afford or do not have the space to keep a bicycle to use them. Additionally, they remove people´s fear of having the personal bicycle robbed.

While different types of solutions are being proposed to promote bike usage, especially for daily commute to replace cars, several barriers are creating difficulties in the change. One of them is the risk perception associated with riding a bicycle in the middle of the traffic. Thus, improving the perception of safety is essential to the adoption of bikes as a replacement of private vehicles.

1.2 Goals and challenges

This thesis aims to contribute to the adoption of bicycles as essential transportation means, by providing to the rider's information that makes them feel safe.

There is a need for encouraging people and giving them all the conditions to feel comfortable and safe while riding the bicycle. However, designing a system to improve the safety perception of bike riders is a demanding task. Different types of challenges need to be taking into account [5]. Designing a system for a one bicycle one in one single road with only one other vehicle requires a few sensors and computation capabilities, and the main challenges arises from the autonomy of the system. Still, when the scale increases and there is the need to start adapting to the real world, with many different routes, with different conditions, neighbourhoods, cities, with many different kinds of vehicles and entities like pedestrians, further analysis has to be done. Information about road quality can influence the ride and cyclist comfort. This information might include the pavement quality, the road slope and everything related to the nearby environment, like noise, pollution or temperature and humidity. Predict other vehicles movement and inform the rider about that, as well as about the existence of vehicles in blind spots can defend the rider of dangerous situations. Also important is to inform other vehicles' driver about the bicycle existence and signal them its movement. In this case, additional sensors are needed, data fusion, efficient information processing and communication capabilities are needed to provide just-in-time and accurate information.

1.3 Thesis contributions

This thesis intend to develop a safety system that gives more information to the rider from the rear angles.

Although the proposed architecture comprises a complete system that covers every functionality needed, in terms of validation, the main contribution of this thesis is the development of the device that gathers sensor information, which is mounted in the bicycle under the seat.

1.4 System overview

The system is composed by a device that is mounted under the bicycle's seat, a user-interface application running on a smartphone that is fixed in the handlebar and a remote server where the information is stored. As stated before the main contribution of this work is the device, This device includes different types of sensors necessary to give information to the riders about other vehicles and also actuators that will give visual information about the bicycle movement to the other vehicles. The device will continuously send the information to the smartphone.

1.5 Document organization

This thesis is organized in different chapters as follows:

- Chapter 1 is a introduction about the topic, about urban mobility and the bicycle users daily challenges. In this chapter is also described the project goal.
- Chapter 2 is the state of the art where it is studied the technologies and methods to measure distances and object detection, the most used communication standards in Internet of Things (IoT) application as well as the processing units used. In this chapter it is also described the worked done in the field.
- Chapter 3 presents the requirements and specifications as well as the architecture of the proposed system, and network.
- Chapter 4 describes the Hardware and Software design in order to implement the system.
- Chapter 5 presents the experiments and the final results of the final solution developed.
- Chapter 6 presents the conclusions and the future work to be developed.

2

State of the Art

Contents

State of the Art

This chapter is organized in three different sections: the first section describes existing technologies and techniques, not only in terms of sensing but also in terms of communication and computational units; the second section analyses different bike system by studying the most relevant related projects and products. The chapter ends with a synthesis and discussion.

2.1 Technologies

It is important to study the working principles of the different technologies, and identify the most important characteristics that are going to be fundamental for the system´s design, similarly to [6]. So, this sections aims at describing the most relevant technologies for our system. In section 2.1.1, it starts by the study of the sensing technologies that are relevant in the context of safety and comfort systems. After, in section 2.1.2, location techniques are described, giving a global view and description about the different methods used. The communication technologies that might be used in a mobile environment are described in section 2.1.4. It is also important to describe the different options for the computational unit and the main options available. Section 2.1.5 addresses these topics.

2.1.1 Sensors

A sensor is a sophisticated device that can measure a physical quantity like speed or pressure by converting a signal that can be measured electrically. Sensors are based on several working principals and types of measurements. There are two classes of remote sensing technologies that are differentiated by the source of energy used to detect a target: passive systems and active systems. Passive systems detect radiation that is generated by an external source of energy, such as the sun, while active systems generate and direct energy toward a target and subsequently detect the radiation.

In this section the majority of the distance measurement sensors emit signals and measure the reflection to make measurements. With so many models available, that use not only different methods but also different technologies, there is the need to study and compare the different solutions. This analysis will be made taking into account different features such as the type of sensor, the accuracy, the resolution, the range, the control interface, the way its working behavior changes with the environmental condition, the calibration and the cost. Since it is going to be placed in a bicycle it is also important to analyze the energy consumption, because it is going to be battery powered. For the same reason it is relevant to study the size and the format to be practical and possible the fixation of the device. [7]

2.1.1.A Techniques for distance measurement and object detection

There are many methods used to determine the distance to objects or obstacles. The devices can be classified according to some basic characteristics, that can be useful for comparison and selection. The devices can be divided in two big groups, the ones that use contact-based methods and the ones that use contactless techniques. The first group can be extremely accurate and is widely used in industry. The contactless techniques, which are the ones of interest for the project, are many and varied. With a range from centimeters to meters, most of them do not approach the accuracy of some contact-based devices. Contactless distance measurement can be divided into active and passive techniques, that were previously explained. An active approach allows a greater degree of control over factors that can influence a measurement, such as ambient illumination, weather and atmospheric conditions [8].

With very few exceptions, the many classes and instances of this ranging devices are based on one of the following three basic principles: When energy propagates at a known, finite, speed (e.g., the speed of light, the speed of sound in air), when energy propagates in straight lines through a homogeneous medium and when energy fields change in a continuous, monotonically decreasing, and predictable manner with distance from their source. The techniques associated with these basic phenomena are referred to as Time-Of-Flight (TOF), triangulation, and field based, respectively [9]:

Time-of-Flight: TOF systems may be ”round-trip” systems (with echo, reflection), that effectively measure the time taken to travel from a reference source to a partially reflective target and back again, for an emitted energy pattern. The devices can use radio frequencies, light frequencies, or sound energy.

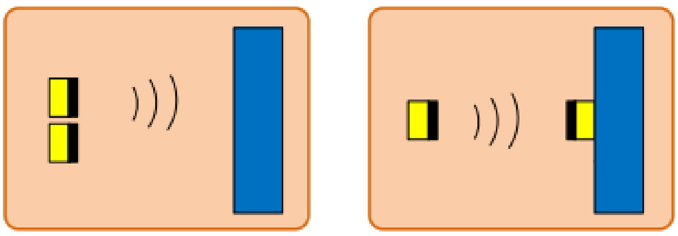

Figure 2.1: Time-of-flight ”round-trip” method (left) and ”one-way” method (right). [10]

The other type, ”one-way” systems (with an active target), transmit a signal at the reference endpoint and receive it at a target endpoint. In order to establish the TOF there is the need of some form of synchronizing reference that must be available to both endpoints. A characteristic of many TOF systems is that their range resolution capability is based solely on the shortest time interval they can resolve, and not the absolute range being measured. That is, whether an object is near or far, the error on the measurement is basically constant. Figure 2.1 illustrates the TOF principle previously described.

Triangulation: The triangulation method is based on the idea that if it is known the length of one side of a triangle and its angles, it can be then calculated the length of the other sides. The "baseline", the name that is given to the known side, is used as a reference. Two points are fixed and known in the baseline, with a known distance from one point to the other. It is then measured the angle by an observer in each of the two points, represented in 2.1.

$$R = bsen(\alpha_{left})sen(\alpha_{right})/sen(\alpha_{right} - \alpha_{left}), \quad (2.1)$$

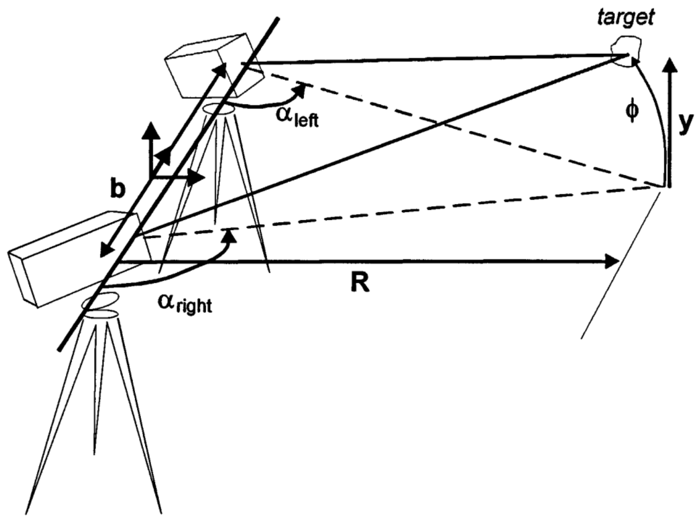

Figure 2.2: Triangulation method. [9]

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Field-Based: The field-based approaches make use of the spatially distributed nature of an energy form while the TOF and active triangulation techniques employ the wave propagation phenomena of a particular energy form. The working behaviour of this method consists in the variation of the intensity of an energy field that usually changes as a function of distance from its source. Therefore if the field generator is known and the spatial characteristics of the field that it produces are predictable, with the measurements of the remote field it is possible to get the information to determine the distance from source.

2.1.1.B Sensor types

Ultrasound: US sensors have a wide use in mobility applications, in terms of distance measurement, obstacle avoidance and vehicle detection as it is possible to observe in the analysis made in [11]. This kind of sensors measures the distance to an object by using sound waves. The principle is based in the TOF method, with the emission of a sound wave at a specific frequency and the respective reception of the sound wave after bouncing back an object or a surface. By recording the elapsed time between the sound wave being generated and the sound wave bouncing back, it is possible to calculate the distance between the sonar sensor and the object [12]. The sound travels through air at a speed about 344 m/s, by determining the time since the wave sound was emitted till the moment the wave is received in the receiver and multiply it by the speed value, it is possible to determine the total round-trip distance of the sound wave. As explained before, round-trip means that the sound wave traveled two times the distance to the object before being detected by the sensor, it includes the 'trip' from the sonar sensor to the object and the 'trip' from the object to the US sensor (after the sound wave bounced off the object). Therefore in order to determine the distance to the object it is necessary to divide the round-trip distance in two. The use of round-trip provides a fairly good estimation of the distance as long as one of the objects is fixed or the relative speed is constant [13]. There are plenty of advantages regarding these types of sensors. In terms of ambient conditions, US sensors have usually a good response to perturbations such as the existence or non existence of light. One of the advantages is also the cost when compared with other technologies, comparison that is going to be made further in this chapter.

Infra-red: The Infra-Red (IR) sensors are also based in the TOF method, and are usually used in applications such as distance measurement and proximity detection, and basically consists of two elements: one IR source and one IR detector. The source includes a LED and although it looks like a normal LED, its radiation is out of the visible spectrum, therefore it is not possible for the human eye to see it. The detector includes a photo-diode that detects the emitted and reflected wavelength. By determining the intensity of the received light it is possible to calculate the value of the distance [14].

These kind of sensors usually offer a fast response and are usually associated to lower costs, compared with other types of sensors. For these reasons they are more commonly used in applications such as obstacle detection in robotics and in the automobile industry. Despite the advantages, there are some problems and difficulties associated with IR sensors caused by their non-linearity in terms of behaviour, their dependence on the reflection of the surrounding objects and respective surfaces and the existence of some external source of light.

RADAR: RAdio Detection And Ranging (RADAR), like the name suggests, is an object-detection system that uses radio waves to determine the range, angle, and velocity of objects. It can be used to detect different types of objects, such as air-crafts, ships, guided missiles, motor vehicles, weather formations and terrain [15] [16]. An elementary form of RADAR consists of a transmitting antenna emitting electromagnetic radiation generated by an oscillator of some sort, a receiving antenna, and an energy-detecting device, or receiver. A portion of the transmitted signal is intercepted by a reflecting object (target) and is re-radiated in all directions. it is the energy re-radiated in the back direction that is of prime interest to the RADAR. The receiving antenna collects the returned energy and delivers it to a receiver, where it is processed to detect the presence of the target and to extract its location and relative velocity.

The distance to the target is determined by measuring the time taken for the RADAR signal to travel to the target and back. The direction, or angular position, of the target may be determined from the direction of arrival of the reflected wave-front. The usual method of measuring the direction of arrival is with narrow beam antennas. If relative motion exists between target and RADAR, the shift in the carrier frequency of the reflected wave (Doppler effect) is a measure of the target's relative (radial) velocity and may be used to distinguish moving targets from stationary objects. In RADAR systems that continuously track the movement of a target, a continuous indication of the rate of change of target position is also available.

Although the different types of information that can be extracted from a well-designed modern RADAR, one of its most important functions is definitely the measurement of range. There seems to be no other competitive techniques which can measure range as well or as rapidly as a RADAR can. Besides that, RADAR does not depend on ambient radiation, as do most optical and IR sensors. RADAR can detect relatively small targets at near or far distances and can measure their range with precision in adverse conditions, like rain, fog or dust, which is another advantage when compared with other sensors. There are usually concerns related with the exposure of electromagnetic fields, however the transmitted power of a RADAR sensor is limited by regulations to few milliwatts, and it is certified to be below the Maximum Permissible Exposure (MPE).

LIDAR: LIght Detection And Ranging (LIDAR) is a method used to measure the distance to a target by emitting light, in the form of a pulsed laser, and measuring the reflected pulses with a sensor. Differences in the return times and wavelengths of the laser can then be used to make digital 3-D representations of the target. In general it is possible to say that this active remote sensing technique is similar to RADAR but uses laser light pulses instead of radio waves. This technology is commonly used not only to make high-resolution maps, that have applications in many different fields, such as geology or forestry, but also in navigation and control systems for some autonomous vehicles. The three-dimensional coordinates (latitude, longitude, and elevation, the x,y,z axes) of the target objects are computed from: the time difference between the laser pulse being emitted and returned; the angle at which the pulse was "fired"; and the absolute location of the sensor on or above the surface of the Earth.

LIDAR systems, like RADAR, are able to work properly by night, however its working behaviour is affected by adverse conditions such as rain and fog, which means that this kind of sensors must be used in fair weather conditions, contrary to RADAR. The cost of the sensors is an important factor, and in this field there are some differences between LIDAR and RADAR, with the first one being usually more expensive then the second one.

Stereo Vision: Many animals, like the human case, have binocular vision where two eyes are used simultaneously to obtain visual information about the environment. The two images obtained are then processed by the animal‘s processing unit, the brain, that use both pictures information to infer depth information. This is an important human characteristic that facilitates the interaction with the world. This technique is also used in the computational field, usually denominated Stereo vision, and is the technique for building a three dimensional description of a scene observed from several viewpoints, based in the triangulation method. It is considered passive if no additional lighting of the scene, for instance by laser beam, is required. So defined, passive stereo vision happens to be very attractive for many applications in automotive industry or in robotics, including 3-D object recognition and localization as well as 3-D navigation of mobile robots. Most of the existing work and research on the subject has been related to binocular vision in which two cameras are used to observe the same scene from two slightly different viewpoints. When the two image points are identified as the correspondent of the same physical point is then computed the coordinates of the physical point. In the algorithm used in [17], after detected the object on the left camera and the algorithm finds a similar object on the right camera, the distance can then be calculated. Even though the used method is based in a simple algorithm, the calculated distance can be accurate.

One of the main advantages of using this technology in this application is the possibility to not only give information about the distance and the objects in the rear angle, but also give the real image to give a different perception to the user. One of the main disadvantages of this technology is related with the cost since it is necessary to have two similar quality cameras.

2.1.2 Localization technologies

GPS The Global Positioning System (GPS) is a satellite navigation system that provides to the user global position and time in every type of climate conditions [18]. The GPS system consists of three ”segments”: the Control Segment, the Space segment and the User segment. It is only possible to operate in an accurate and reliable way if these three segments are properly controlled. The control system is composed of many monitoring and control stations around the world and its main goal it is to monitor the satellites, reporting the results to the main control center, and relaying the control signals generated back to the satellites. This Segment is responsible for detecting satellites that are not broadcasting properly, or that are not in the proper orbit, and commanding the satellites to identify themselves as unhealthy when circumstances warrant. This allows the Control Segment to keep results obtained from using the system consistently within operating specifications. The Space segment is composed by a group of satellites, defined as 24, but it is possible to be more or fewer at any one time. The constellation is orbiting the earth and are at a distance approximately 20,000 km above the earth. The satellites have different kinds of orbits that permit the receivers located at most spots on earth be able to see at least 6. The User segment is the term used to identify all the receivers that are listening to the satellites at any time. The user receivers are all passive, they don´t have the need to broadcast anything, which means that they don´t interfere with each other making the systems accessible to any number of users.

The operation of this system is based in a mathematical principle called ´trilateration´. When the receiver tries to locate itself, it finds out the three nearest satellite and calculates the distance between itself and one of the satellites. The distance measured ´X´ is then used as the radius of a drawn sphere that has this satellite as the centre of it. This process is then repeated for the other two satellites. Out of these three draws two possible positions are possible to be taken, although one is located in the space, which means the other one is the receiver´s location. To increase the precision of the location the receiver usually tries to locate more than four satellites. To communicate the Satellites use low power, high frequency radio signals, and the distance is calculated by knowing the time the signal took to reach the receiver.

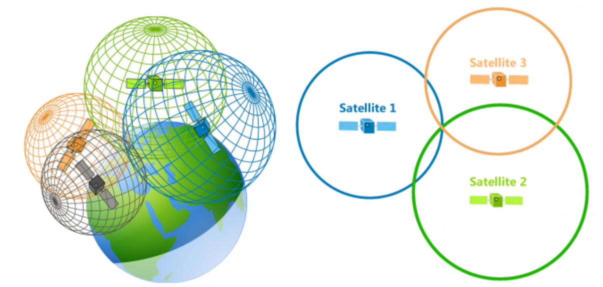


Figure 2.3: Trilateration method for global positioning. [19]

The GPS accuracy can have typicallly an accurancy of 5 meters in a normal smartphone with the integrated GPS. There are other positioning method used in the world, the russian Glonass and the european Galileo. Glonass is the one that has the lowest performance although that difference can not be well recognized by normal smartphones. On the other hand Galileo promises to be the most accurate, using more clocks and with a better precision in which satellite. From all this devices, GPS is the one that has more compatible devices, but with the increasing of usage of Galileo, more devices are going to be prepared in the future to use it.

2.1.3 Multi-sensors systems for autonomous driving

Self-driving vehicles have different types of objects to track and to identify. There are a lot of vulnerable and even unpredictable entities, that have different trajectories, movements and velocities. In order for a solution of this kind be deployed in real-world driving environments, autonomous vehicles must be capable of interacting in a safe way with nearby pedestrians and other kinds of vehicles. To achieve these kind of safe interactions the prerequisite is a reliable detection and tracking of moving objects. For that reason, there is the need to have complex systems that usually are a fusion of different sensors technologies, previously studied. As it was possible to conclude, there are technologies that have different characteristics, such as range or time of response, and sometimes the best solution is not choose the most complete or the one with better results. Due to such a critical role this topic as in the scientific community, it has been extensively studied for the last decades.

MultiSensor for obstacle detection: In [20] it was developed a sensing system with the underlying ideas of minimize the alterations in the vehicle appearance, completely cover the area around the vehicle, with a certain range and utilize existing sensors. The sensors installed in the vehicle chassis were six RADAR's, six LIDAR's and three cameras. With this sensors layout, an object within 200 meters will be projected onto the sensing coverage and an object within 60 meters or so will be detected by at least two different types sensors, RADAR and LIDAR or RADAR and camera. A similar system was developed in [21], where the picture 2.4 was taken and where is possible to observe the sensors layout. There are represented two stereo cameras (in red), on the front and on the back, for long range narrow angle detection, four fisheye monocular cameras (in blue) for all-round view obstacle detection and short range collision avoidance sonars (in green).

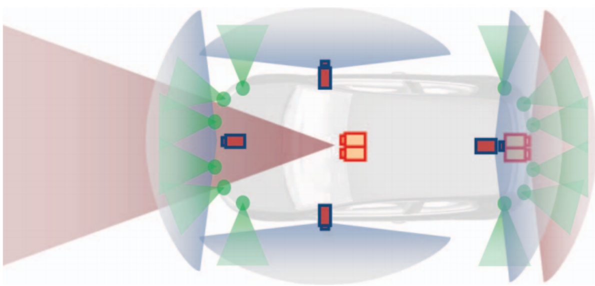


Figure 2.4: System sensors layout. [21]

In [20] it was a great challenge to perfectly fuse measurements from 14 different sensors and generate consistent tracking results over time. In figure 2.5 it is possible to see the diagram that describes the tracking system that consists in two main parts, sensor and fusion layer. The sensor layer takes care of the hardware specific operations, which offers a separation between the sensing hardware and specific tasks regarding detection and tracking for objects. In this way, it is possible to perform and develop the tasks in the fusion layer without knowing the details about the lower-level´s mechanisms. Each sensors is responsible to acquire raw data and extract features in the case of existence. This data is then published in a shared communication channel and picked up by a task at a higher-lever, fusion layer, for its purpose. Based on lower-level´s features it is possible to execute point or box models to track features of time. This system was chosen to be described because it was the most relevant in the topic.

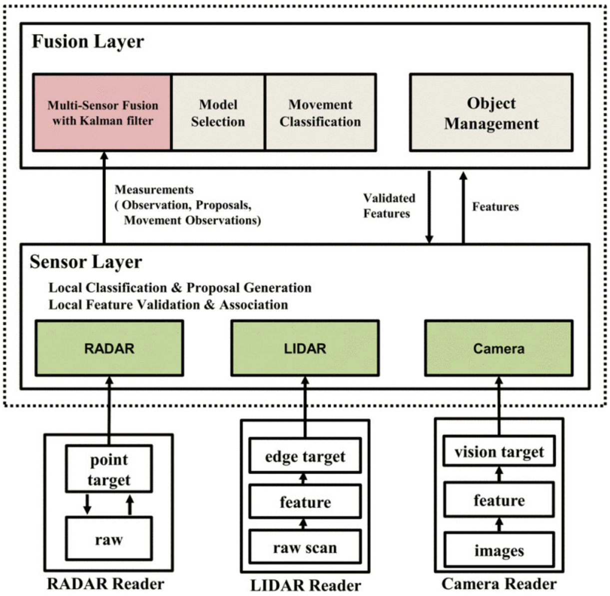


Figure 2.5: Tracking system diagram. [20]

2.1.4 Communication technologies

There are many reliable and wireless communication technologies, some that are more limited than others, in terms not only of range, speed and even price. This approach has some advantages but at the same time there are some disadvantages, regarding the comparison with cabled networks. One of the main advantages is the mobility, where there is not the need for plugging. In wireless networks the new users can join or leave the network dynamically which permits move among different environments. Despite that there are different challenges that no always are simple to solve. Comparing with cabled networks, wireless are less reliable due to the existence of interference. Other problems are related with power consumption, that is a big concern for this project, as well to possible data security threats and lower data rates. With that said there is the need to study and analyze some of the most used protocols and of course, the most relevant for this project.

2.1.4.A Personal area network technologies

Bluetooth - IEEE 802.15.1 standard: The well known protocol BT, which the original idea was conceived in 1994, is an IEEE standard (802.15.1) for wireless communications based on a radio system designed for short-range cheap communications devices suitable to substitute for cables for peripherals such as printers, faxes, joysticks, mice or keyboards. The devices can also be used for communications between portable computers, act as bridges between other networks, or serve as nodes of ad-hoc networks. This range of applications is known as Wireless Personal Area network (WPAN). BT defines a whole communication stack that allows the different devices to find and communicate with each other.

A device using BT can either operate as a master or as a slave. The simplest configuration of a Bluetooth network is called piconet, that basically is a WPAN, and has a maximum of eight devices, seven active slaves and one master. A piconet is defined by a frequency-hopping channel that is based on the master´s address. All the devices that are participating in communications in this type of network are synchronized by the master´s clock. It is possible to have different piconets connected with each other, which form a scatternet. This type of topology can be used to build a multihop wireless network, which means that at least two nodes can communicate even though there is not a direct connection between them, which allows the possibility that the information could flow beyond the coverage area of a single piconet. In the case of a scatternet, a node can be a slave in several but a master in only one. Besides operating in the active mode, where communication take place, a slave device can also in the parked or standby mode in order to reduce power consumption.

The original used modulation method was Gaussian Frequency Shift Keying (GFSK) scheme which was the only scheme of modulation available by the time. Since the introduction of BT 2.0+Enhanced Data Rate (EDR), modulations such as 8-Differential Phase Shift Keying (DPSK) and π/4-Differential Quadrature Phase Shift Keying (DQPSK) can also be used between devices that are compatible. Devices that are functioning with GFSK are operating in basic rate mode in which an instantaneous 1 Mbit/s data rate is possible to achieve. In the 8-DPSK and π/4-DQPSK schemes is possible to achieve 2 Mbit/s and 3 Mbit/s respectively.

Initially the concept of Quality of Service (QoS) was only related with the maintenance of the communication between devices and the respective error occurrence and packet loss during the process. But besides that, there was the need to take into attention other issues such as congestion control of the network and the service differentiation. For each communication session, the QoS parameters can be negotiated between the user and the network, depending the available resources and requirements. Providing QoS guarantee means that it is possible to assure a consistent and predictable network performance. The application layer QoS is affected by different parameters such as bandwidth, which can influence delays in data transfers. An application can specify the needed bandwidth or can be derived the application requirements for delay. This parameter is mostly determined by the algorithms polling performed by the master of the piconet. Other parameter is related with the delay that is caused by the available bandwidth, referred before, and the re-transmissions. The Synchronous Connection Oriented (SCO) traffic has priority over the Asynchronous Connection-Less (ACL) traffic, which can also increase the ACL traffic delay. There are some real-time applications that require the fewest possible delays. The other important parameter is Reliability that is related with the data arrival. There are some applications that are more error tolerant that others, increasing this parameter has consequences for the bandwidth and the delay [22].

Since BT is designed to be used in short-range communications, its nominal range is reduced compared with other standards, like the Wi-Fi. As it is possible to conclude from different studies, such as in [23] the nominal range is of 10 m. BT works in the 2.4 GHz band, which is an unlicensed band and in most of the European countries, such as the case of Portugal, 79 channels are allocated, each one them 1 MHz wide.

Like mentioned before, in order to reduce power consumption, a slave device can be in the parked or standby mode. The power requirements of BT devices are also significantly lower than compared with other standards. The typical current absorbed is comprised between 1 mA and 35 mA depending the usage mode.

BLE - IEEE 802.15.4 standard: BLE is a BT version specified in the version 4.0 with low energy consumption. This emerging wireless technology is intended to be used for short-range communication with the special concern in the energy consumption. The appearance and creation of this standard occurred to create single-hop solutions for many different fields such as health-care, consumer electronics or security. The potential of BLE and its use and adoption is also increased by the similarities with the classic BT, which make it even easier to use and implement with devices that usually deal with this technology and are already prepared for it, like smartphones, laptops and even some development boards [24].

Similar to the classic BT, the BLE protocol stack, figure 2.6 is mainly composed by two main parts, the controller and the host. In the controller there are the two lowest layers, the Physical and the link layer. Usually is implemented as a small System-on-Chip (SOC) which has an integrated radio. The physical takes care of transmitting and receiving bits. The link layer provides medium access, connection establishment, error control, and flow control. The host includes upper layer functionality, such as Logical Link Control an Adaptation Protocol (L2CAP), Attribute Protocol (ATT), Generic Attribute protocol (GATT), Security Manager Protocol (SMP) and Generic Access Profile (GAP). In terms of communication between the Controller and the Host is standardized as the Host Controller Interface (HCI). Other functionalities, like the application layer that is not defined by the BT specifications, are used on top of the host. The communication between a device that only implements BLE with a device that only implements classic BT it is not possible. For this reason, devices such as smartphones have implemented both BT and BLE, those kind of devices are called dual-mode devices.

BLE also supports multiple network topologies, including a point-to-point option used for data transfer, a broadcast option used for location services and a mesh option used for creating large-scale device networks. The usual data rate is often inferior compared with BT, from 125 Kb/s to 2 Mb/s. The eLPRT protocol is an enhanced version of the Low Power Real Time (LPRT) protocol. In comparison with the Medium Access Control (MAC) protocols defined by the IEEE 802.15.4 standard (Zigbee), it introduces several mechanisms designed to increase the reliability against errors, improve the bandwidth utilization and increase the number of supported devices [25]. The coverage range is typically over various tens of meters but it is usually utilized in small range applications.

In terms of the physical layer, BLE operates in the same band of classic BT, in the 2.4 GHz Industrial Scientific Medical (ISM). 40 Radio Frequency (RF) channels are defined, with a 2 MHz channel spacing and are divided in two different types, the advertising channels and the data channels. Advertising channels are used to discover other devices, to connection establishment and broadcast transmission. The data channels are used for bidirectional communication between connected devices. In the 40 channels, 3 are defined as advertising and the other 37 as data channels. All the physical channels use a GFSK modulation, which is simple to implement and allows a reduced peak power consumption.

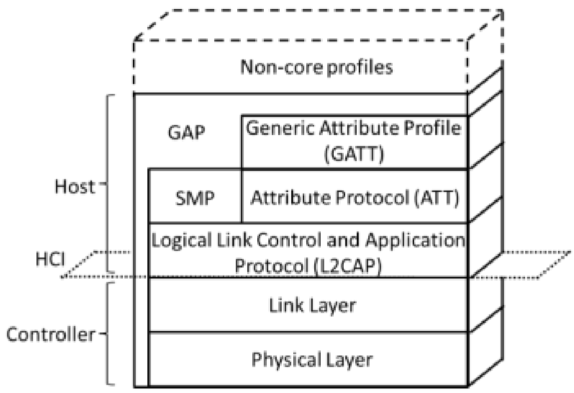


Figure 2.6: BLE protocol stack. [26]

In terms of saving energy, there are mechanisms that allow and maximize it. By default, the slaves are in a sleep mode and wake up periodically in order to listen to possible packets reception. It is the master that determines the moments in which the slaves need to listen. It is also the role of the master to provide all the needed information for the frequency hopping algorithm. The usual energy consumption goes from 1mW to 50 mW, with a maximum peak current consumption of 15 mA, depending on the used mode.

Although both BT and BLE have a lot of aspects in common, there are others where both standards differentiate. Both are intended to be used in different contexts, BT can handle more data while consuming more energy. BLE is used for applications that do not need to exchange large amounts of data, and can therefore run on battery power for more time, with less costs. One of the main differences is the fact that a BLE device remains in a sleep mode constantly except for when there is the need to initiate a connection. The actual connection times are of a few mS, while BT would take around 100 mS [27].

Zigbee ZigBee defines specifications for low-rate WPAN for supporting simple devices that have minimal power consumption and typically operate in small distances. The major features included in this standard are low power consumption, the possibility to have a plenty of nodes close together, with that a high density network, low costs and simplicity in implementation. These features are possible to achieve due to the characteristics ZigBee possess. In terms of topology, there are different possibilities such as: star, mesh and peer-to-peer as it is possible to observe in figure 2.7. For transfer reliability it uses a fully hand-shake data transfer protocol.

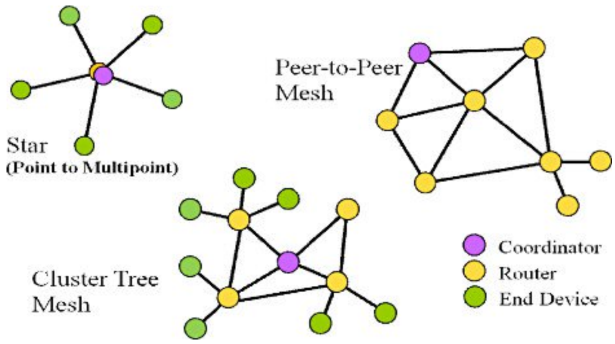


Figure 2.7: Types of topologies in Zigbee networks. [28]

The maximum data rates allowed for each of the frequency bands are fixed, 250 Kbps for 2.4 GHz, 40 Kbps for 915 MHz, and 20 Kbps for 868 MHz. The existence of a high throughput and low latency for low duty-cycle applications (¡0.1%) and the use of Carrier Sense Multiple Access with Collision Avoidance (CSMA - CA). The addressing space can be of up to 18,450,000,000,000,000,000 devices (64 bit IEEE address) and 65,535 networks.

The range can go from 5m to 500m depending on environment but the typical is 50m. It operates in three licence-free bands: 2.4-2.4835GHz, 868-870 MHz and 902-928 MHz. Each of the bands have a different number of allocated channels, that are respectively, sixteen (numbered 11-26), one (numbered 0) and ten (numbered 1-10). One important characteristic is the wise use of the battery, that permits a low power consumption. With this characteristic is possible to have long battery life, from months to years. It is possible to achieve this by either two means, with a continuous network connection and a slow battery drain, or an intermittent connection with a slower battery drain.

2.1.4.B Local area network technologies

Wi-Fi - IEEE 802.11 standard: The IEEE 802.11 standard, commonly called Wi-Fi, aims to provide wireless connectivity to devices that require quick installation, such as portable computers or generally mobile devices inside a Wireless Local Area Network (WLAN). It defines the MAC procedures for accessing the physical medium, which can be IR or radio frequency. Mobility is handled at the MAC layer, so handover between adjacent cells is transparent to layers built on top of an IEEE 802.11 device [23].

A Wi-Fi WLAN is based on a cellular architecture, where each cell is called a Basic Service Set (BSS), that is a set of mobile or fixed Wi-Fi stations. Access to the transmission medium is controlled by means of a set of rules called a coordination function. The simplest network configuration is the independent BSS, which implements an ad hoc network topology comprising at least two stations. no structure exists, so creating a multihop network requires higher-level protocols. Alternatively, an infrastructured BSS may be part of a wider network, called extended service set (ESS). An ESS is a set of one or more infrastructured BSSs connected via a distribution system, whose nature is not specified by the standard: it could be a cabled network or some other type of wireless network; 802.11f specifies the inter-AP protocol. The stations connected to the distribution system are the APs. Services offered by the stations fall into two classes: station services and distribution system services. The latter are offered by the APs, and allow data transfer between stations belonging to different BSSs. The standard also defines the functions of the portal, which is a bridge for interconnecting a Wi-Fi WLAN with a generic IEEE 802.x LAN.

Wi-Fi provides for different degrees of QoS, ranging from best effort to prioritized and, in infrastructured networks, guaranteed services. Usually Wi-Fi is used in small distances applications but some can go up to 100 m. The available bandwidth is divided into partially overlapping channels. All the devices in the same BSS (either infrastructured or ad hoc) use the same channel. Depending on the version, different techniques are used for multiplexing, which leads to different transmission rates. Wi-Fi use a spread spectrum technique in the 2.4 GHz ISM band, like BT and BLE which ranges from 2.4 to 2.4835 GHz, for a total bandwidth of 83.5 MHz, it is also possible to operate in the 5 GHz band.

A Wi-Fi device may be in either the awake or doze state. In the doze state the station can not either transmit or receive, which reduces power consumption. Consequently, there are two power management modes: active mode and power save mode. The handling of the stations in PS mode differs according to the topology of the Wi-Fi network. A Wi-Fi device typically requires between 100–350 mA.

Wi-Fi variants: Wi-Fi technology provide a huge range of versions, that basically differ on the frequencies used, coverage range, throughput, as well as QoS and security features. Different modulation and coding schemes allowed the evolution of the standard.

2.1.4.C Wide area networks

Cellular networks - ITU-T standards: Cellular networks are distributed over geographical areas, called cells, and are usually used to provide network coverage used for long range transmission of voice and other types of data. Cellular networks are designed for coverage areas that can be national or even global.

Cellular networks are a distinct and important network topology as it was possible to characterize in [29]. Cellular mobile-radio network consists in a network of radio base stations forming the base station subsystem. The core circuit switched network for handling voice calls and text. A packet switched network for handling mobile data The public switched telephone network to connect subscribers to the wider telephony network. This network is the foundation of the Global System for Mobile communications (GSM) system network, which is implemented in a vast amount of mobile phones globally. There are many functions that are performed by this network in order to make sure customers get the desired service including mobility management, registration, call set-up, and handover.

Any phone connects to the network via a radio base station at a corner of the corresponding cell which in turn connects to the mobile switching center. The center provides a connection to the public switched telephone network. The link from a phone to the radio base station is called an uplink while the other way is termed downlink. Radio channels effectively use the transmission medium through the use of the following multiplexing and access schemes: frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), and space division multiple access (SDMA).

There have been different types of cellular generations that use different types of modulations and can accomplish different speed, with the most recent in use being the 4G that can reach very high speed data. Cellular access technology continues to improve at rapid pace, with existing Long Term Evolution (LTE) standard deployments capable of supporting data rates up to 100 Mbps [30].

In mobile networks QoS refers to the measurement of transmission quality, service availability and minimum delay of the system. There are different schemes that provide QoS in this type of networks. The Fault Tolerant Dynamic Allocation scheme is responsible for the methods of reusing the channels effectively between two cells that are separated by a minimum distance in order to not interfere with each other. Here The channels are allocated dynamically. There is also the Call admission control scheme which employs pre-blocking of calls based on the available bandwidth for handling calls. In the Mobility Prediction Techniques hand off losses are reduced and due to which the blocking and the dropping probabilities are significantly reduced. Other technique, called renegotiation scheme, the bandwidth allocation is changed dynamically based on the availability.

When joined together, these cells provide radio coverage over a wide geographic area. This allows communication between portable devices and fixed transceivers and telephones anywhere in the network, via base stations, even if some of the transceivers are moving through more than one cell during transmission. Major telecommunications providers have deployed voice and data cellular networks over most of the inhabited land area of Earth. This allows mobile phones and mobile computing devices to be connected to the public switched telephone network and public Internet.

A cell typically uses a different set of frequencies from neighboring cells, to avoid interference and provide guaranteed service quality within each cell. All radio access technologies have to solve the same problems: to divide the finite RF spectrum among multiple users as efficiently as possible. Cellular networks use Frequency reusing, that is the concept of using the same radio frequencies within a given area, that are separated by considerable distance, with minimal interference, to establish communication.

Two factors determine the energy consumption due to network activity in a cellular device. First, is the transmission energy that is proportional to the length of a transmission and the transmit power level. Second, is the Radio Resource Control (RRC) protocol that is responsible for channel allocation and scaling the power consumed by the radio based on inactivity timers [31].

2.1.5 Microcontroller

Microprocessor A Microprocessor is a single-chip CPU and has been present in daily lives for a long time. However, only in the last few years microprocessors have become powerful enough to take on truly sophisticated functions. The increasing of the capabilities and power of microprocessors, driven by Moore´s Law, resulted in the emergence of embedded computing as a field of study. In the early days of microprocessors, when all the components were relatively small and simple, it was necessary and desirable to concentrate on individual instructions and logic gates. Today, when systems contain tens of millions of transistors and tens of thousands of lines of high-level language code, there are certain design techniques that help deal with complexity [32].

Microprocessors come in many different levels of sophistication and they are usually classified by their word size. An 8-bit microcontroller is designed for low-cost applications and includes on-board memory and I/O devices. A 16-bit microcontroller is often used for more sophisticated applications that may require either longer word lengths or off-chip I/O and memory. A 32-bit RISC microprocessor offers very high performance for computation-intensive applications. The use of microprocessors instead of other digital systems, like custom logic or Field Programmable Gate Arrays (FPGA), for exemple, is related with the fact fact that microprocessors are a very efficient way of implementing digital systems. Besides that, designing this kind of systems makes it easier to design other kinds of products that can have different features.

Embedded Systems There are many types of computer systems, the ones that are relevant for this project are designated as embedded computer systems. This definition includes the devices that are programmable computers but that are not intended to be a general-purpose computer.

Embedded computing systems have to provide sophisticated functionality:

- Complex algorithms: The operations performed by the microprocessor may be very sophisticated. Usual examples are related with the automobile industry like the case of a microprocessor that controls an automobile engine must perform complicated filtering functions to optimize the performance of the car while minimizing pollution and fuel utilization.
- User interface: Microprocessors are frequently used to control complex user interfaces that may include multiple menus and many options. A good example of sophisticated user interfaces are the moving maps in GPS navigation.

Embedded computing systems are usually must often be performed in order to meet deadlines:

- Real time: Many embedded computing systems have to perform in real time. If the data is not ready by a certain deadline, the system breaks. In some cases failure to meet a deadline is unsafe and can even endanger lives. In other cases, missing a deadline does not create safety problems but create failures in the system that can decrease the quality.
- Multirate: Not only must operations be completed by deadlines, but many embedded computing systems have several real-time activities going on at the same time. They may simultaneously control some operations that run at slow rates and others that run at high rates. Multimedia applications are prime examples of multirate behavior. The audio and video portions of a multimedia stream run at very different rates, but they must remain closely synchronized because failure to meet a deadline on either the audio or video can ruin the presentation.

Another important aspect is the Cost of the system, and there are different kinds of costs that have to be taken into account:

- Manufacturing cost: The total cost of building the system is very important in many cases. Manufacturing cost is determined by many factors, including the type of microprocessor used, the amount of memory required, and the types of I/O devices.
- Power and energy: Power consumption directly affects the cost of the hardware, because a larger power supply may be necessary. Energy consumption affects battery life, which is important in many applications, as well as heat consumption, which can be important even in desktop applications.

Real Time Operating Systems A preemptive Real-Time Operating System (RTOS) solves the fundamental problems of a cooperative multitasking system. It executes processes based upon timing requirements provided by the system designer. The most reliable way to meet timing requirements accurately is to build a preemptive operating system and to use priorities to control what process runs at any given time. This two concepts are used to build up a basic RTOS. There are different RTOS available and open source, such as FreeRTOS, that runs on many different platforms [32].

2.1.5.A Communication Interfaces

This interfaces connect the microcontroller to the peripherals, such as the sensors of the system. Most of the I/O interface circuits are included on chip.

2.1.5.B SPI - Serial Peripheral Interface

SPI is a synchronous serial communication interface specification that is usually used for short-distance communication between the microcontroller and one or more peripherals. This protocol uses a Master-Slave topology, which means that the microcontroller will have a master role, generating the clock signal that control the data exchange between the other devices, slaves. The communication with SPI is full-duplex type due to the fact that the data can be transmitted and received simultaneously. This protocol has four different connections:

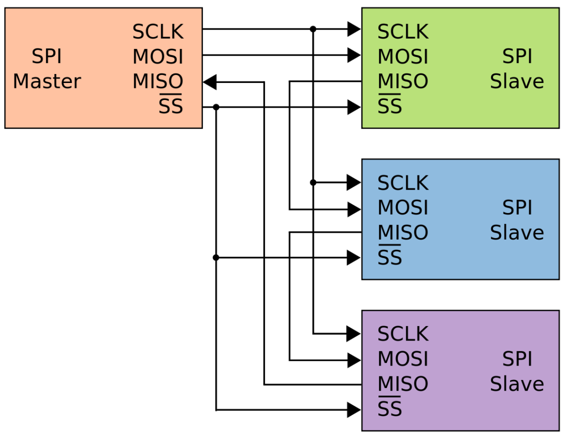


Figure 2.8: Serial Peripheral Interface (SPI)

- Master In Slave Out (MISO): Data from Slave to Master;
- Master Out Slave In (MOSI): Data from Master to Save;
- Serial Clock (SCK): Generated by the master to synchronize the data transfer;

- Slave Select (SS): Select the slave to communicate;

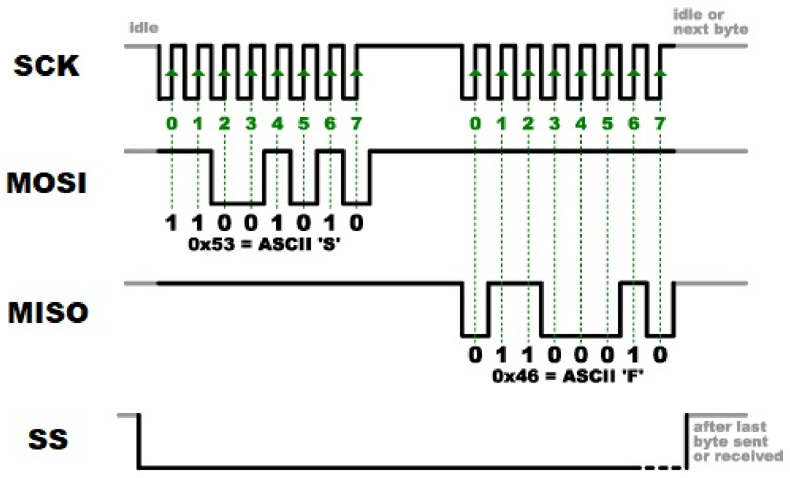


Figure 2.9: Serial Peripheral Interface (SPI) data transfer

Each slave is selected by a low logic level ('0') via the SS line. It is possible to observe that that in order to begin a communication, the master sets the clock using a frequency less or equal to the maximum frequency the slave supports.

The main advantage of this protocol compared to other serial communication protocols, is the fact it is possible to achieve high data rates. One of the main disadvantages is the fact that SPI does not have acknowledgment of the received, making it impossible to confirm if the data is correct. Another possible disadvantage regards the fact that it is possible to have one master, however if it only necessary to have one master this is not a problem.

2.2 Smart mobility systems

In this section there were studied different systems with different purposes and developed works. Since the bicycle and gadgets market is a big market and the tendency is to grow even more, there is the need to evaluate solutions that are available in the market and that have already, besides the related academic work in the topic. The different systems are described and classified into two different categories depending the type of application. The solutions that intend to transform the bicycle into a smart vehicle, presented in the section Smart Biking (2.2.1), the solutions that intend to improve the safety not only of the rider but also of the bicycle, presented in the section Safety Systems (2.2.2).

2.2.1 Smart Biking

The smart biking systems contemplate a group of functionalities that allow an improvement in the ride quality through different characteristics and features that are described in this section. The systems are divided in two groups: one with the system embedded in the bicycle, and the other, with systems that are installed in a common bicycle. In this sections the most relevant systems from each group are analyzed and described.

2.2.1.A Nireeka

Nireeka is a smartbike that has a set of built-in features aimed to improve the bicycle´s comfort for the user. Included in the system, there are also mechanical features that, although very interesting, are not relevant for the project, like suspension and brakes systems. The functionalities provided by the bicycle built-in features are accessible by using the personal mobile phone as the central processing unit and display. The system has four main components: the phone mount/charger, the app, the blind spot RADAR, the anti-theft system and the hearbeat system. These components are detailed in the next paragraphs.

The system has a phone mount that can be used with every type of phone. It also has a charger that keep the device charged up as the user rides. This permits the use of the user´s personal smartphone as the interface of the system.

To control the system and display all the information to the user there is an iOS/Android App. The connection to the embedded system in bike is made through Bluetooth. The app is used not only for navigation but also to control the light and to monitor all the information, like the speedometer, battery monitor and the RADAR information.

Nireeka has two US sensors on the bike´s rear axle to help the rider avoid cars and pedestrian collision. The information is given to the user through an app that runs in the user´s smartphone. The idea is to inform the rider from the existence of something or somebody in the blind spots and works in a simple way, using only two indicators in the app, one that represents the left side, and the other the right side. This system prevents unauthorized access to the bicycle. Upon detection of theft it raises the alarm/flasher and notify the user with details like geographical locations, time stamp and state of the bike. It is possible then track the bike using the app.

Nireeka has also a feature that allows the rider to use a mode that will help him when his heartbeat level raises. The higher the heartbeat, the higher the system helps the user by increasing the motor power. It possible to calibrate for which heartbeat values which power percentage is given to the motor.

2.2.1.B COBI.bike

COBI.bike is a device, from COBI.bike GmbH, that is integrated into an existing bike that turns the bicycle into a smart vehicle [33]. The system aims to improve the ride, not only in terms of comfort but also in terms of experience. COBI.bike enables the connection of the bike to the digital world through the use of the rider smartphone which provides an intuitive hands-free dashboard and is the central processing unit of the system. The system has four essential components: the charging mount, the biking app, the ambiSense light system and the safety and security system. They will described in the following paragraphs.

In order to have the central unit in a good position for the user, COBI includes a hub that is installed in the handlebar, using a robust screw-on mechanism, that allows to fix the smartphone. This hub securely holds, protects, charges and manage the phone while cycling. The system is continuously charging the phone while riding. The regular version has a rechargeable battery pack that extends the phone battery life. If the bike is equipped with a hub dynamo it is possible to charge the battery pack while riding.

Figure 2.10: Cobi.bike charging mount system. [33]

The core component of the system is implemented on a smartphone. The different features can be controlled with a thumb controller that is installed in the handlebar in order to maintain the driver´s attention on the road. The COBI dashboard gives the user access to speed, weather, fitness and performance info in a well organized and optimized interface. The system has a feature that allows the user to play music from local music to the most common media apps, like Spotify. It is also possible to make and take calls by selecting the option with the thumb controller. The systems has some sensors integrated that display real-time data like cadence, performance, and heart rate zone, calories and ascent directly on the dashboard. The connection between those sensors and the smartphone is done through Bluetooth. COBI also integrates other apps like Strava, Google fit and Apple Health in order to track the rides automatically.

The light system is inspired in modern cars and makes sure that the rider is always visible to others. The sensor-based smart lighting has three different modes for different conditions: daytime running, low-power beam, and full beam. The modes can be controlled manually or can set to automatic mode where the systems turns on the lights when it gets dark. The rear light is wireless integrated with the system and it is turned on with the front lights. It also has turn signals that can be triggered from the handlebars.

The system also provides some features that aim to increase the ride safety, as well the equipment safety. COBI includes a smart alarm system that detects suspicious movements. When selected in the app, the hub detects and reacts sensitively to suspicious movements. When something is detected the alarm is activated, besides that the light starts flashing. To increase the protection when the system is installed, the personal phone is the only device that can connect with the COBI hub. Besides that the system has a feature that wakes it up and welcomes the user when approaches the bicycle with the phone. To increase the security while riding, there is an integrated electronic bell that can be triggered using the thumb controller. With this, it is possible to warn pedestrians when needed.

2.2.1.C SmartHalo

SmartHalo is a device that is installed in the bicycle handlebars that aims to turn the bike into a smart vehicle [34]. It consists in a circular shape device with a circular digital display that transmits the different kinds of information using lights associated with movements. The system has four essential components, these components are: navigation, ligh systems, safety and fitness tracking. They will be detailed next.

The system has navigation incorporated and has different modes. It is possible to set the final location and select the mode where the system will indicate where the user should turn. In the other mode the user will always know in which direction the final destination is and where to turn. It is also possible to know the last bicycle´s location.

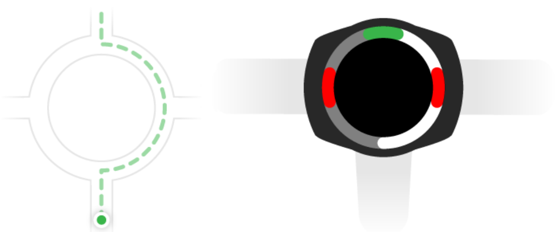


Figure 2.11: SmartHalo navigation system. In the left a route example of a roundabout and in the right the indication from the device. [35]

A good example of the navigation can be seen in roundabouts, that are common in Europe. Having a circular interface can be an useful to display which exit to take. When arriving at a roundabout, SmartHalo mimics the roundabout and its multiple exits, which allows the user to understand which one should be taken.

The system has a light that turns on automatically when the ambient light is insuficient, it also shuts down when the ride ends. SmartHalo has an internal motion sensor that is used to trigger an alarm in case of a persistent meddling. To deactivate the alarm when recognizes the user smartphone, and in case the phone is not working it is possible to tap the custom code.

It is also possible to track the user´s fitness activity and to check the progress. Information like speed is also available. The system includes an app where all the information can be stored and visualized. Besides all that SmartHalo also includes features that allows the user to maintain the phone in the pocket but still be able to check information like call and sms notifications.

2.2.2 Safety systems

The safety systems contemplate a group of functionalities that aim to improve the physical safety of the bicycle as well the road safety. The systems are divided into 2 groups, one whose systems are intended to assure the physical safety of the bicycle and the system, throw lockers and tracking systems, and the other which the goal is to improve the road safety, in terms of the rider perspective. In this section there are devices that are installed in an existent bicycle and there are systems that are embedded in bicycles. The most relevant systems from each group are going to be analyzed and described.

2.2.2.A Bike safety systems

Linka Smartlockers: Linka Smartlockers are physical lockers that are designed with the main goal o improving the physical safety of the bicycle. To preserve the material and protect it from possible thefts, the use of lockers is a common practice, Linka´s products guarantee a certain level of safety while adding technology and new features in terms of unlocking and connection to the locker. The locker is fixed in the bicycle frame and can be use also without the phone, with a code, which allows to unlock even when the battery is low, even tough a single charge can last several months and the app warns the user when the battery is low [36].

Figure 2.12: Linka Smartlocker. [36]

The system is key-less and uses the user´s smartphone as the key and the locker controller. Besides all the mechanic characteristics, that make the system not only durable but also convenient and fashionable, the solution offers characteristics like GPS tracking, embedded in the locker, as well as a siren that sounds in case of theft. The theft attempts can be detected using the accelerometers. The locker unlocks when the rider is closer to the bicycle and the connection between the phone and the locker is made through a Bluetooth connection. It is possible to share with other people the possibility to unlock the same locker which it makes it even easier and convenient to use.

ofo: ofo is a bike-sharing system that uses a security system, embedded in the bicycle that aims to secure the physical safety of the bicycle. In terms of technology the system is based on an app for the smartphone that allows the user to find bicycles around him, choose a bicycle and unlock it using a QR code system. When the trip is finished it is only necessary to park the bicycle and block it.

The system was a very successful product, but currently, the site is unavailable.

2.2.2.B Road safety system

Varia Rearview Radar: The Varia Rearview RADAR is a device, made and patented by Garmin [37], and is a cycling RADAR with the main goal of creating a safer cycling environment in terms of road safety. The purpose of this device is to warn the bicycle rider of vehicles approaching from behind up to 140 meters. It is designed as a wireless autonomous system with a compatible Edge cycling computer, that can detect multiple vehicles and indicates the relative speed of approach and threat level. The embedded light also warns the approaching drivers of a cyclist ahead.

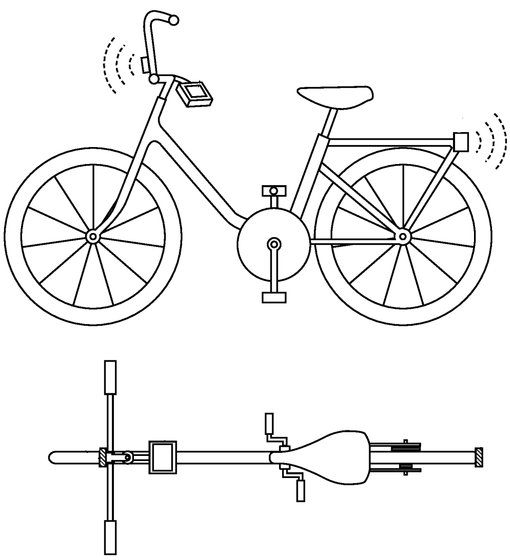


Figure 2.13: Varia system fixation in a bicycle. [37]

The mobile electronic device includes a position-determining component for determining a current geographic position of the bicycle, a wireless transceiver for receiving RADAR sensor data from a RADAR sensor in the RADAR sensor housing, a display, and a processor coupled with the position-determining component, the wireless transceiver, and the display. The processor is configured to determine one or more situational awareness indicators based on the received RADAR sensor data and cause the display to present location information and the one or more situational awareness indicators.

Biketastic: Biketastic [38] is a mobile app and a platform that aims to improve the riding quality and safety by analyzing the travelled routes and by sharing data and results. The information is shared by the members of the community through their mobile app. Using this app the users are able to share the routes, ride statistics and sensed information that can be used to classify the route. The route profile and dynamics that characterize it are obtained using the accelerometer and microphone from the phone. With these sensors is possible do determine the road roughness and the general noise. The final part of the user experience is obtained from the users that capture media such as photo or videos with a geographical tag. This information is uploaded to the platform that contains a map-based system that allows an easy and convenient visualization and information sharing among community members.

BikeNet: BikeNet [39] is a mobile sensing system for mapping the cyclist experience. It uses a number of sensors that are embedded in the bicycle and collect data. The data collected is not only to give information about the cyclist performance, as a user-targeted application, but also to collect data from the environment and the route. The interest in this project is due the fact the system contributes the first working mobile networked sensing system.

The system architecture offers a people-centric paradigm for large-scale sensing at the edge of the Internet using an opportunistic sensor networking approach. This approach leverages mobility-enabled interactions and provides coordination between people-centric mobile sensors and static sensors, and includes edge wireless access nodes in support of sensing, tasking, and data collection. Figure 1 shows an overview of the system where is possible to see the different types of components of the architecture.

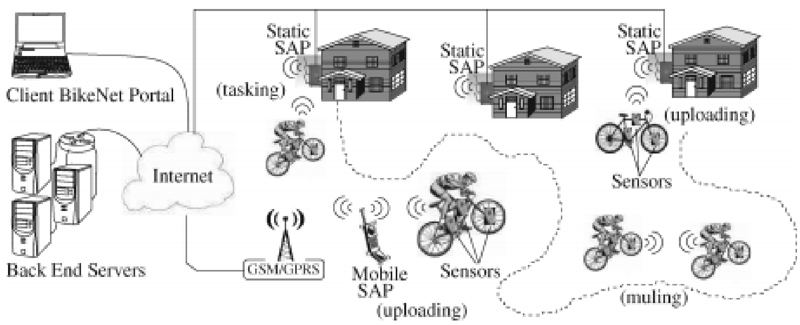


Figure 2.14: BikeNet System Architecture. [39]

The system is organized into three layers, the backend layer, the Sensor Access Point (SAP) layer, and the mobile sensor layer. Mobile sensor: Data concerning cycling performance, cyclist health and fitness, and the environment surrounding the cyclist´ routes is gathered through Moteiv Tmote Invent [Moteiv Tmote Invent 2007] mobile sensing platforms. These platforms are not only installed in the bicycle but also in the cyclist himself. The sensors used are the ones that are provided in the used platform such as: two axis accelerometer, a thermistor, a photodiode and a microphone.

The developed mobile phone application collects GPS data (latitude, longitude, and speed) every 1 second. As said before the phone´s microphone and accelerometer are sampled to determine route noise level and roughness. In order to find the areas that have excessive noise levels the phone samples its audio stream and every 1 second the maximum value is obtained. This maximum values are usually associated to areas where there are large vehicles or heavy traffic. To determine the existent of bumps and the road quality the values from the acceleration variance of the different axis towards earth are monitored using the accelerometer. To validate the results and to adjust and take into account the phone position in the begging of the usage the application goes trough a calibration phase. The mobile phone collects the data and it is uploaded to a backend sensor storage database. When the route is completed a series of processing operations are performed in order to gather the information, use it and display it.

2.3 Synthesis and discussion

This section summarizes the main results of chapter and discusses the most suitable options for our system design.

2.3.1 Technologies

A bike safety system requires an adequate selection of different type of technological components, such as sensing, location, communication and computation. They were described in the section 2.

Regarding the sensors, a multiple sensor system seems more adequate to support different set of actions. From the sensors studied, the most adequate are the US sensors, for side-detection of obstacles, a RADAR for long-distance obstacle detection and a camera form object recognition and rear-view.

The GPS system although not indispensable for object detection might be useful, in order to keep track of rider position. In order to reduce power consumption, other option might be the use of the mobile system GPS. However, it will not be possible to track the bike when no mobile phone is available or when it is not in use.

Concerning the communication technologies, two different scenarios are foreseen: gathering data from the sensors to the mobile phone and sending information to a remote center. BT or BLE are widely used technologies, being the most adequate options for mobile phone communication. As far as remote communication is foreseen Wi-Fi and cellular networks can be used, depending on the environment. There are some multi-protocol wireless network interface cards that are prepared to connect a device to others using different standards, like the ones studied above. This solutions have particular interest because they allow the system to become able to connect with different types of devices, vehicles and networks.

The use of a single-board computer allows an easy integration of multiple sensors, while providing access to a set of communication technologies and allowing a great flexibility in terms of design. Examples of available devices are the Raspberry pi or Arduino platforms. As major disadvantages, when compared to a dedicated hardware, is the cost and the power consumption of the final solution. Independently of the final decision, the use of real-time operating system is mandatory in order to allow the implementation of the safety systems that must be provided.

2.3.2 Systems

Several systems have been proposed to address mobility or byke safety. The most relevant ones were described in the section 2.1.5.B.

After analyzing the systems there are several characteristics that can be taking into account. Tracking and vehicle recognizing techniques from systems like Nireeka and Garmin Rearview RADAR [37] it is a characteristic that has to considered. Collecting data from the city in order to have the maximum amount of information and be able not only to help the user but also the entities that are responsible for territorial planning of the cities. In this category biketastic [38] and bikenet [39] are important projects.

The main problems to solve are mainly connected with the rider safety. From the analyzed solutions it is possible to conclude that even with some work, sometimes the information gathered from the rear angle sensors is not conclusive and it is not possible to predict if it is a vehicle or other kinds of objects. One of the main problems found is the way the information is displayed to the user. In some cases the user has to concentrate in the display and loose the concentration from the road. The energy usage is also a problem that can be found in some solutions. The use of a battery without a way of restoring its energy limits the amount of time that is possible to use the system. To turn the system more sustainable and able to be used for long periods of time, energy harvesting techniques can be used since there is a considerable amount of mechanical energy produced by the rider.

3

Architecture

Contents

Architecture

In this section it is described a proposal of the system's architecture in terms of functionalities and components to be developed.

The first step is to identify the requirements. After that, specifications are set, which create a more detailed description of the desired system and the architecture is defined. The chapter ends with a summary section.

3.1 Requirement analysis - interview process

Before designing the system, it is essential to understand what does the prospective users feel regarding bicycle usage as the transportation mean. For this, a set of informal interviews have been made, and the complete process and findings presented next.

This stage capture this information by gathering an informal description from potential users: bicycle riders that have different goals and use the bike differently.

3.1.1 Methodology

We want to understand what are the difficulties perceived by the citizens that constrain the adoption of bicycles. Instead of focusing our study on the general population, we decided to start by the earlier adopters, since these are the one that might trigger the behavioural change. So, we selected restricted type of bike users: some that use the bicycle on daily commutes; others that use it for recreation purpose, and others that are athletes and have to train every day.

To capture the problems that these users faces, instead of having a questionnaire, we decided that the interviews were done with informal conversations, using the design-thinking approach [40]. These conversations must be focused on a set of topics to allow the comparison of the different perspectives. Our focus is the riders' experiences, things and features that they would like to have in their bicycle, and the consequences and bad aspects of moving around in a city by bike. This way, we guarantee that we gather similar information from different persons.

During each interview, notes have been taken with the main ideas conveyed and the perception of the person. These notes are registered as a card per person, with all the identification information that allows us to repeat the process during the project development, every time will need to validate an idea. So, people were informed about the non-anonymous nature of the interview process before starting it and the possibility of follow up meetings.

The volunteers were asked different questions such as in [5]. Firstly in order to understand their characteristics and in which group they were in terms of bicycle usage it were asked several questions regarding personal information and bicycle usage. It was required what were the sensations while riding a bike, the major concerns, positive and negative aspects and their personal opinion regarding what could be changed in order to improve the riding experience.

3.1.2 Report and analysis

There interviewed 20 people, that are characterized as follows:

- Age: 50/% people from 20 to 30 years old and 50/% people from 31 to 50 years old;
- Gender: 12 males and 8 females;
- Type of user: 4 athletes that practice almost everyday, 2 people that use the bicycle everyday day to go to the work place, 6 people that usually ride only during the weekend and eight people that use the bicycle once or twice during a month.

The number of interviews is small, but by the time the process was done (examination period near Christmas holidays) not enough people were able to participate. Nevertheless, based on the analysis of the notes taken during this process, we were able to capture some findings and insights.

The majority of the people reported as the main problem the perception of danger. Nevertheless, when entering into details during the conversation, the concerns are different. Next follows the most important findings:

- The majority of the interviewed people were concerned to ride a bicycle next to a car that weights some tons and that move at a really high velocity.
- Some concerns are related with some motorized vehicles drivers attitudes, and that sometimes drivers do not respect the cyclist space. Among these users there are the ones that do not respect the signals, that usually use the telephone while driving or that simply do not respect other drivers and speed limits.
- Other concern is related with the environment and road conditions that everyday some riders have to face in their daily commute. Some would like to register and have access to the information

about the environmental conditions, like the air quality or humidity of the roads in order to choose the best one.

- Other users are more excited with other features more related with the performance such as to know the exact speed and cadence to have a determined velocity and energy management.

The most important and common topic in the interviews was safety, either related to the cyclist or the bicycle. The same topic is mentioned in several mobility studies [41], [42] and [43]. So, this means that safety might be the key feature that need to be added to a bicycle to promote its usage.

3.2 Functional requirements

The insights that were given by the interviews allow is to specify the functional requirements of our system. Here there are some specifications and characteristics that can be implemented:

- Give the rear and lateral information to the cyclist, including an image of the back view;
- Signalize the cyclist position and trajectory, including brakes light and blinkers.
- Track the bicycle and the system remotely to increase the security;
- Detect possible user falls in order to warn the emergency contacts if necessary;
- Sense and control the environmental values, related with ambient conditions and pollution;
- Easy installation and adaptation to the bicycle.

From all this set of possible feature, it was decided to select the two main characteristics since we are developing a proof-of-concept of a minimum viable product and not a complete system. These two characteristics were found the most crucial, giving the rear and lateral information and signalize the rider position and trajectory . Nevertheless, the architecture must be designed in a modular and flexible way to allow the addition of new sensors and more complex algorithms.

3.3 System architecture

The entire system comprises three components: the Bike device, the End-user device and the Remote server, as depicted in figure 3.1.

The bike device system is installed in each bicycle to gather sensor information needed to provide safety information to the rider by means of warnings events.

The user device is used to interface with the rider, warning them about safety conditions, provide location and time information, needed to correlate different events and communicate with a remote server.

The remote server stores the information received by any driver so that it can be processed and use by a central entity.

Next paragraphs will detail each one of these components.

Note that, although a highlight of the global architecture is presented, the main contribution of the thesis will be the bike device system.

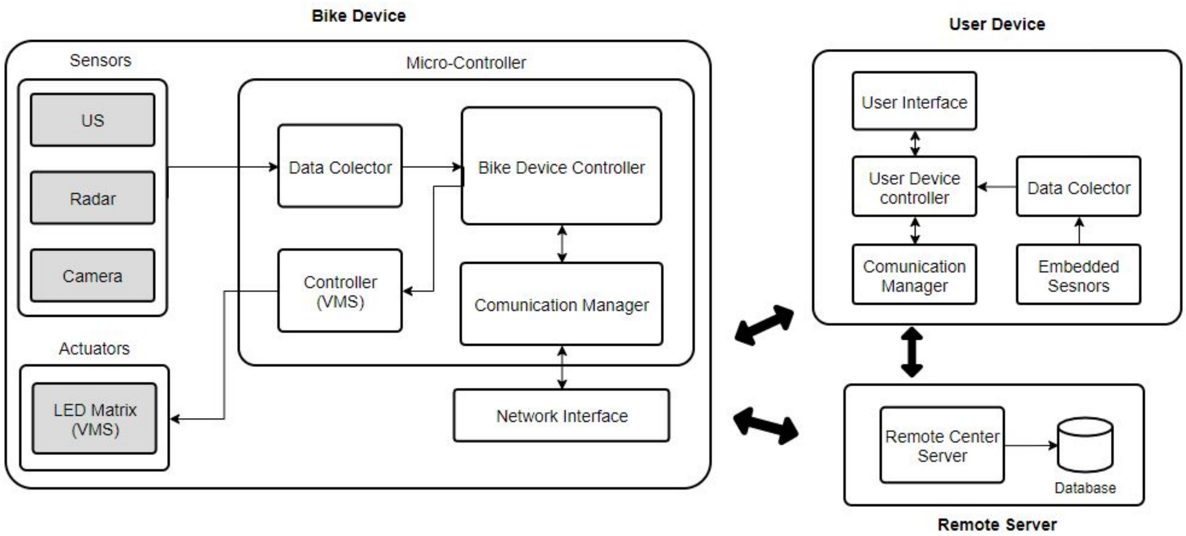


Figure 3.1: System Architecture

3.3.1 Bike device

The bike device is the core component of our system. It must be a portable and easily installed in the rear part of the bike under the seat.

The bike device is responsible improving safety by allowing biker and driver to know about the presence of each other. For this, it will collect and process the data from sensors and control the actuators. Its main block is the Bike device controller, that coordinates the entire system.

This device connects with the user smartphone using a BLE connection or wi-fi, and with a remote center using Wi-Fi or cellular network. The selection of the communication technology is performed by the network manager.

Sensor information is used to inform the biker about rear safety conditions caused by obstacles and nearby vehicles. For this, multiple sensors are needed to detect and recognized objects, such as US sensors, RADAR and camera, as well as GPS system. Information retrieved from sensors is gathered by the Data collector.

Actuators are from used to inform pedestrians and drivers about the bike movement. They comprise a rear light systems, lane changing and stop signal. At this phase, our first idea to provide a simple interface, is to use a led matrix system to implement a variable message system, controlled by its own controller.

3.3.2 End-user device

The user's smartphone is used as end-user device. It provides the interface with the biker through an application. This interface maintains biker informed about rear driving conditions.

Sensors available at the end-user device, such as accelerometers, gyroscope and magnetometer, may also be used to enrich the information gathered by the bike device. In this case, this information can be used to automatically detect bike movement pattern and control the actuator accordingly without the need to install additional sensors in the front part of the bike.

This device is connected with the bike device so that users can receive general information and safety warnings from the bike device, as well as sending the necessary commands to control it. End user device may also communicate with the remote server to transfer user and/or mobility information.

3.3.3 Remote server

The remote server is used to control the entire system and store users, bikes and general mobility information gathered by the different bike devices. Bike devices and users communicate with the remote center using Wi-Fi or cellular network. It is also possible to communicate with the authorities and emergency contacts. Due to the complexity of the system and the existent limitations the remote server will not be developed.

3.3.4 Synthesis and discussion

Although the design of the Architecture contemplates all the functionalities, this thesis will focus on the development of the bicycle device, leaving the other components as a proof of concept. For the bike device, the electronic components are going to be studied and chosen and then the circuit designed. After the hardware development, the focus is the software development, implementing all the desired functionalities. It is then necessary to test and evaluate the system characteristics in terms of performance, and in this field there are two major concerns, the system's autonomy and how it is mounted on the bicycle.

4

Bike device implementation

Contents

4.1 General design options

After analyzing the different technologies and designing the system architecture it is necessary to choose and define the different components that will be used.

As stated before, the main component of this thesis is the bike device system. For the implementation there were two different options that could be chosen: using an off-the-shelf board or develop a custom board for the project. There were available a few of off-the-shelf board that are very flexible, providing the means to develop the required functionalities (and added new more, when needed) within a limited time-frame, adequate for the expected duration of a thesis. Hence, this was the selected option. Later, if the entire system proof to be useful, but very expensive, it can be replaced by dedicated hardware.

4.2 System design - hardware

4.2.1 Microcontroller

The microcontroller processes the data received from the sensors and controls the actuators. It also inform the drivers through the communication interfaces.

The chosen system to use in the prototype is the RPi Zero W for different reasons. The first reason is related with the size, having 65 mm long, 30 mm wide and 5mm thick, which is ideal for the system. Other factor is related with the cost that comparing with other solution available in the market with similar capabilities is low. The connectivity and processing capabilities were also important to made the choice.

Hardware Specifications: The RPi Zero W, a SOC computer, is the central part of the system, it controls the communication with the sensors and actuators, processes the data received and manages the communication with the memory and other devices. The RPi includes a Broadcom BCM2835, 32-bit ARM11 single-core SOC running at 1GHz and it has a 512MB LPDDR2 SDRAM. RPi Zero runs on Linux kernel based operating systems that boot and run from an SD card.

Peripheral Communication interface: RPi has a 40-pin GPIO with different functions, such as the 5 and 3,3 supply voltage that can not only be used to power the RPi but also power other devices. These pins offer a direct connection to the SOC, enabling the communication with other devices using different communication protocols such as Inter-Integrated Circuit (I2C), SPI and serial communication using Universal Asynchronous Receiver/Transmitter (UART). Besides the GPIO, RPi has also different types of connections such as Camera Serial Interface (CSI) and micro Universal Serial Bus (USB). There were chosen different protocols for this project, taking into account the sensors capabilities and the best option in terms of performance. For the camera the chosen protocol was the CSI, a specification

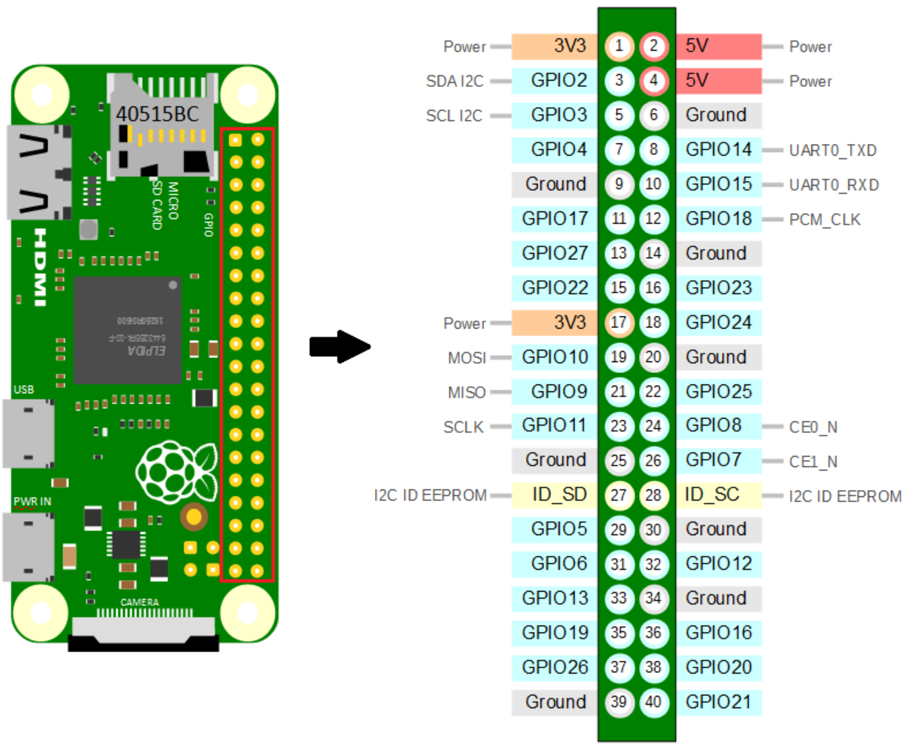


Figure 4.1: Raspberry Pi Zero W GPIO pinout.

	Specifications
Dimension	Height: 65 mm; Width: 30 mm; Weight: 9g
SOC	Broadcom BCM2835
Core	32-bit ARM1176JZF-S Single-Core
GPU	Broadcom VideoCore IV
CPU clock	1 GHz
Random-access memory (RAM)	LPDDR2 512 MB
Wireless Communication	2.4 GHz 802.11b/g/n, BT and BLE

Table 4.1: General specifications - RPi Zero W.

that defines an interface between a camera and a host processor. The choice was due to the power consumption, due to is smaller physical size, a faster bandwidth, higher resolutions, higher frame rates and reduced latency, compared for example USB. To communicate with the US sensors it is used the general purpose pins which are suitable for their behavior.

Connectivity: This generation of RPi is equipped with different communication standards, previously studied in 2.1.4, such as 802.11 b/g/n (Wi-Fi), BT and BLE, which makes it an ideal solution for IoT applications.

4.2.2 Peripheral devices

4.2.2.A Sensor - Ultra-Sound

The ultrasonic sensor used is the Ultrasonic Ranging module HC-SR04, which is widely used for distance measurement, and has a capacity of 2 cm to 400 cm, with an accuracy that reaches 3 mm. This module consists of three parts: the ultrasonic transmitter, the ultrasonic receiver and the control circuit. The transmitter is responsible for emitting the acoustic waves towards an object while the receiver is responsible for receiving the reflected waves. This module was chosen due to its stable performance, for having a good ranging accuracy for the proof of concept of the project as well as a reduced price, which makes the perfect model for building a prototype.

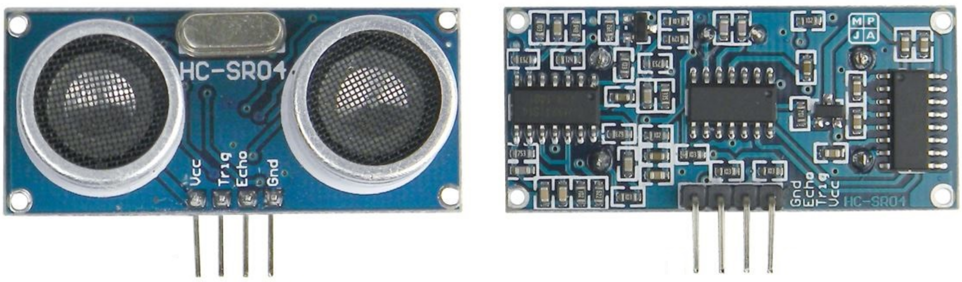


Figure 4.2: US sensor module HC-SR04

This module comprises four different pins that are used for different purposes. The VCC pin which is the power supply for the sensor from the controller. The GND pin that is connected to the ground of the controller. The Trig pin that is used to trigger the ultrasonic sound pulses and the Echo pin, that transmit a pulse when the reflected signal is received.

Operating Principle: The sensor is activated by receiving a high voltage signal of 5V for at least 10 microseconds from an external controller in the Trig pin. After the activation the module sends out an 8 cycle burst of acoustic waves at 40 kHz and waiting to receive the reflected waves, while starting the timer. The 8-pulse pattern allows the receiver to differentiate the transmitted pattern from the ambient ultrasonic noise. Meanwhile the timer is started and the Echo pin is set to high (5V) and postponed for a period (width), which depends directly to the wave's covered length. When the reflected waves are detected by the sensor, the Echo pin is set to low while the current state of the timer is used to calculate the period of the echo signal. The range is then obtained by applying a simple distance-speed-time

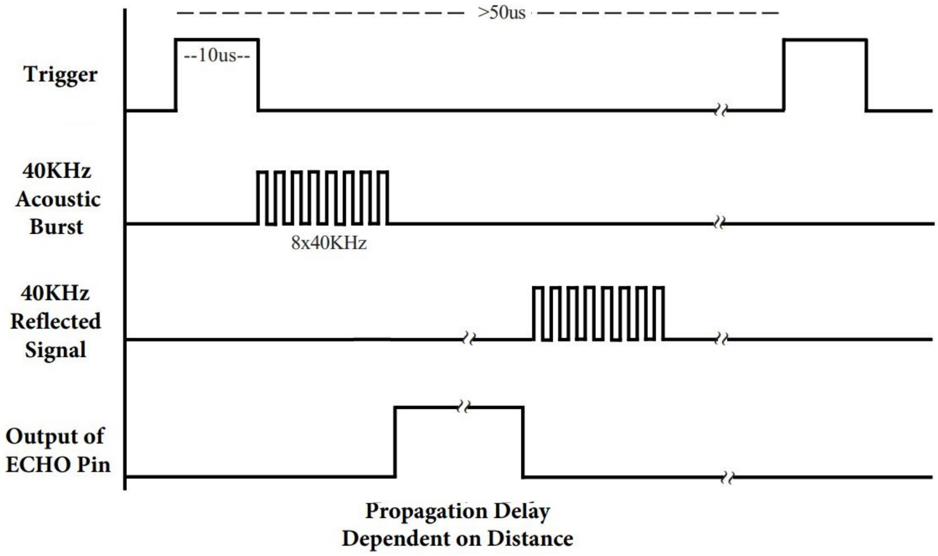


Figure 4.3: Operation principle - US sensor module HC-SR04.

equation, where the speed is the speed of sound, 340 m/s and the time is the time calculated by using the timer. This obtained distance is then divided by 2 since this the obtained time is relative to all the trip from the wave since leaving the emitter.

$$Distance = Speed \times Time, \tag{4.1}$$

$$Distance = 340(m/s) \times Time, \tag{4.2}$$

If the sent pulses are not reflected back, the Echo signal will timeout after 38 milliseconds and return low. This means that a 38 milliseconds pulse indicates no obstruction within the range of the sensor

Pin Symbol	Pin function
VCC	5V power supply
Trig	Trigger Input pin
Echo	Receiver Output pin
GND	Power ground

Table 4.2: HC-SR04 module pinout.

In terms of limitations, there are considerations that have to be done. This module can not measure with accuracy distances bigger than its range as well measure distances between the sensor and objects that don't have a sufficient sized surface to reflect the waves. Other limitation is related with the angle between the direction of the emitted haves and the surface.

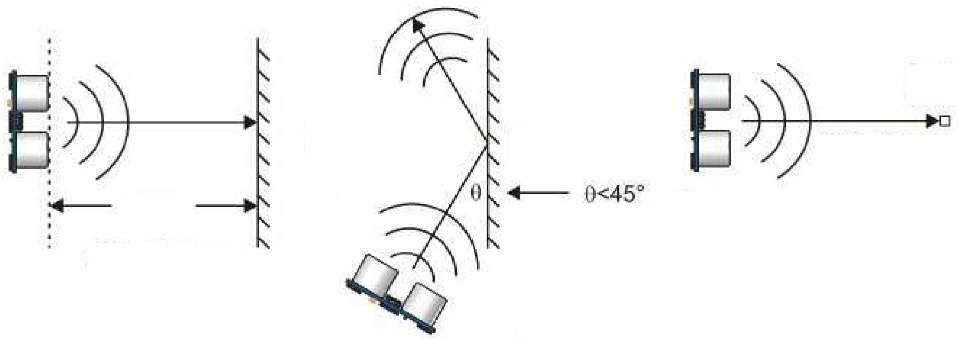


Figure 4.4: Operating Limitations of the US sensor module HC-SR04.

	Specifications
Dimension	Height: 45 mm; Width: 20 mm;
Operating Voltage	5V DC
Operating Current	15 mA
Operating Frequency	40 KHz
Range	0.02 m - 4 m

Table 4.3: General specifications - HC-SR04 module

4.2.2.B Sensor - Camera

It was chosen the RPi camera module that has a Sony IMX219 8-megapixel back-illuminated Complementary Metal Oxide Semiconductor (CMOS) image sensor, a high speed video imaging and high sensitive sensor which is capable of 3280x2464 pixel static images and supports different video resolutions such as 1080p30, 720p60 and 640x480p90. This module was chosen due to its capabilities, due to the its small size, of 25 mm x 23 mm x 9 mm, and and also due to the fact that is a low cost camera sensor.

Image Processing: RPi Graphics Processing Unit (GPU) firmware includes routines for handling the data from the camera module. This feature allows handling the data stream from the sensor, that streams raw pixel data directly to the GPU. The raw images are converted into RGB pictures and processed in order to be displayed with a low latency. The different tools available in the firmware include:

- Black level correction (using non-light-sensitive pixels)
- Lens shading correction (compensates for vignetting on the sensor/lens combination)

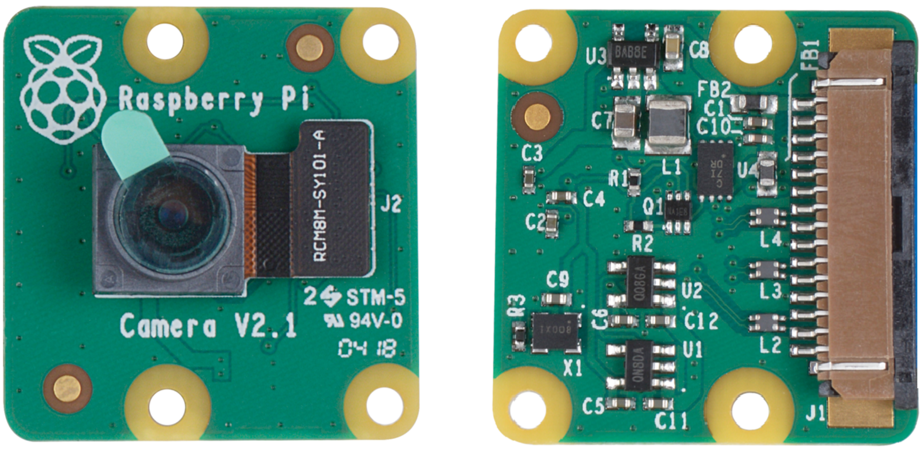


Figure 4.5: Rpi! Camera Module V2.1.

	Specifications
Dimension	Height: 25 mm; Width: 24 mm; Weight: 3g
Sensor	Sony IMX219
Sensor resolution	3280 × 2464 pixels
Video modes	1080p30; 720p60; 640 × 480p60/90
Bus interface	CSI-2

Table 4.4: General specifications - RPi Camera module V2.1

- White balance correction
- De-noising on raw Bayer data
- Demosaicing of the Bayer-patterned image
- Further de-noising on the resulting YUV colour image
- Adjusting sharpness, saturation, brightness, and contrast
- Resizing to the requested resolution

4.2.2.C Actuator - VMS LEDs

As an actuator to give the information of the rider to other vehicles behind it was considered an electronic and intelligent display panel, usually denominated as VMS in road traffic management. One of the main characteristics of a VMS is its versatility, making it suitable for providing information for a variety of situations.

To implement this type of actuator it was chosen a LED matrix, arranged in series of four 8 x 8 dot Matrix, making 32 columns and 8 rows of LED, having a total of 256 LED. As it is possible to observe in figure 4.6 all the anodes of a particular row are connected to one pin as all the cathodes of a particular column are connected to another pin. Therefore this matrix has 8 row pins, R1 to R8 and 8 columns pins, C1 to C8. Consequently to turn on the first LED for example, it is necessary to apply a positive voltage to pin R1 and a negative voltage to C1.

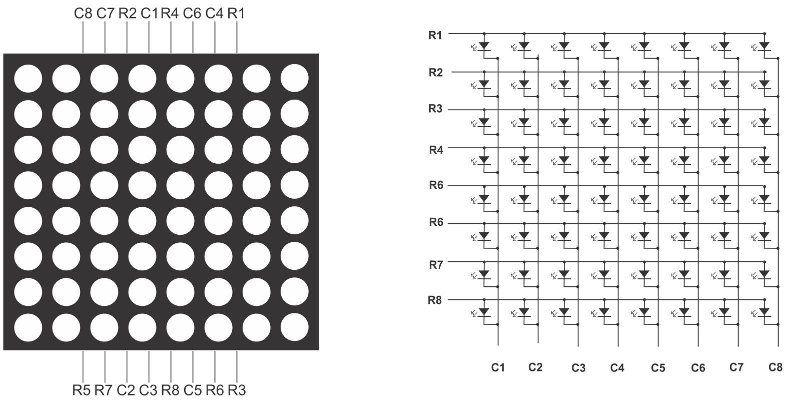


Figure 4.6: 8X8 LED Matrix Display internal circuit diagram.

Although it is possible to turn on and off the LEDs individually by applying positive and negative voltages in each pin, it is not possible to it directly from the GPIO of the RPi, due to the limited size of it. Therefore, to control the panel efficiently it is necessary to have an interface between the LED matrix and the RPi. This interface is accomplished using the MAX7219 IC, a common-cathode display driver (image 4.7).

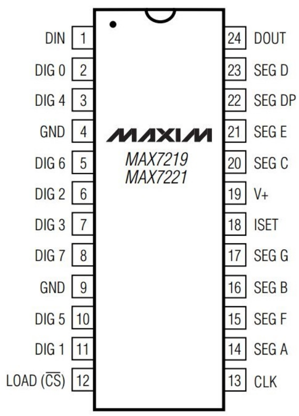


Figure 4.7: MAX7219 IC top view. [44].

Each one of the four 8×8 matrix will have one of this IC with serial input and parallel output that connects the controller to the display. This IC can interface a micro controller to a 7-segment numeric LED display, to bar-graph display or to a 64 individual LED display, which is the case of this project. This IC includes on-chip a binary-coded decimal code-B decoder, multiplex scan circuitry, segment and digit drivers and a static RAM that stores each digit.

Communication: In terms of communication with the RPi it will be accomplished with the display driver 4-wire serial interface allowing to communicate using SPI protocol. One of the main advantages is related with the fact that individual digits can be addressed and updated without rewriting the entire display. It is possible to observe each pin function in table 4.5.

Number	Name	Function
1	DIN	Serial Data Input
2,3,5-8,10,11	DIG 0-DIG 7	Eight-Digit Drive Lines that sink current from the display common cathode
4, 9	GND	Ground
12	LOAD	Load-Data Input
13	CLK	Serial-Clock Input
14-17, 20-23	SEG A-SEG G, DP	Seven Segment Drives and Decimal Point Drive that source current to the display
18	ISET	Connection to VDD to set the peak segment current
19	V+	Positive Supply Voltage
24	DOUT	Serial-Data Output

Table 4.5: MAX7219 IC pin description.

4.2.3 Circuit design

Figure 4.8 describes the schematic of the bike device system. This schema contains the interconnections between the RPi. and the peripheral devices selected.

A few details require extra clarification, namely the US output, power supply and Led matrix drivers.

Appendix A contains a bigger representation of the schematic.

US output: Due to the fact that the US output signal (ECHO) is rated at 5V and the input pins of the RPi GPIO are rated at 3.3V, sending a 5V signal into the unprotected 3.3V input port can damage the

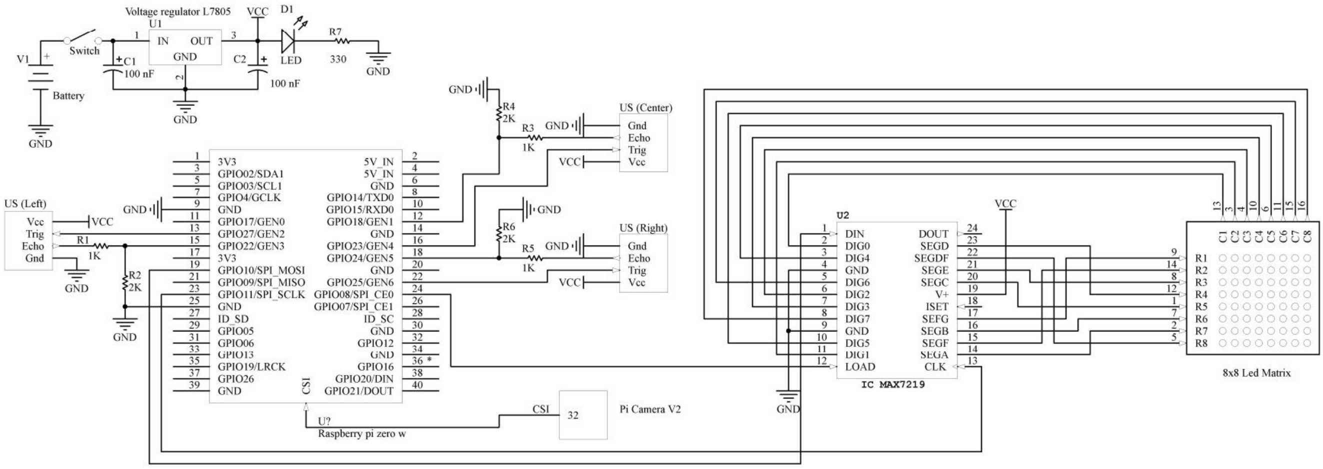


Figure 4.8: System circuit.

GPIO pins. It is then needed to use a voltage divider circuit, consisting of two resistors, to lower the sensor output voltage to an acceptable level. The values of the resistors were defined based on the application of the Ohm's law.

$$V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2} \tag{4.3}$$

The chosen resistors values are 1KΩ and 2KΩ.

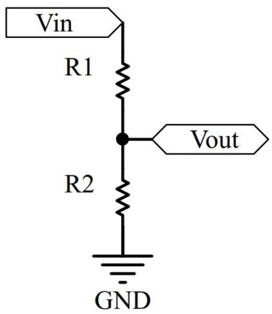


Figure 4.9: Voltage divider.

Supply voltage: To provide a regulated 5V supply it was implemented a voltage regulator that has as input a power source. the chosen regulator is the LM7805 from Texas Instruments and can deliver up to 1.5 A of output current, and has built-in short-circuit protection. In order to maintain the regulator's stability when there are non desired voltage drops in the circuit there were placed capacitors.

LED Matrix driver: The communication between the RPi and the driver, MAX7219 IC, is accomplished using SPI protocol. It allows cascading devices, making possible connecting four 8x8 LED matrices, by connecting the D_{Out} pin of the previous driver to the D_{In} pin of the current one. The other pins are connected in the same way as the previous driver.

4.3 System design - software

4.3.1 Design options

Software design options are essentially related with the selection of the operating system and programming languages or special libraries to be used. Next paragraphs details our options.

Operating system: There are two main options regarding the Operating System (OS) selection: a RTOS or version of a general purpose OS, specially optimized for use with the RPi. We decided to use the last approach because it was considered that it is not crucial for the application in terms of time deadlines and that would had a complexity to the system that until this moment it is not necessary.

Hence, we selected the RPi OS lite (formerly Raspbian OS lite), a Debian-based OS built to run on these SOC computers. It is a 32-bit fork of Debian Linux that is especially optimized for the BCM2835 ARMv11 processor that powers RPi Zero W. There are different versions available, as we do not the necessity to have access to the graphical user interface and the traditional user tools, such as office, we selected the lite version image (Kernel version: 5.4), available at RPi website [1]

Programming language: Regarding the selection of the programming language, two main options are available C or Python.

Although C is a well-adapted for use in embedded systems, we decided to code in Python, a high-level programming language, because it is very easy to use, provides a powerful and very complete set of libraries and is very common nowadays. Python is interpreted, which means when a Python program is executed, an interpreter reads the Python instructions and then performs the desired action. Besides that it is a general-purpose dynamic programming language that focuses on code readability.

Communication: The communication between the bike device and the external components relies on BT/BLE or (eventually Wi-Fi). BT and BLE have their own protocol stack and requires special software libraries to operate.

[1] Rasperry Pi OS image: https://www.raspberrypi.org/software/operating-systems/

It was used BlueZ, an official Linux BT protocol stack in order to provide support for the BT layers and protocols. This stack allows the connections with BLE devices and send GATT requests. To stream video in real time it is used Wi-Fi as it is explained afterwards.

4.3.2 Global system - components and interactions

As previously mentioned, the main goal was to develop the bicycle device. A simplified architecture of the solution that was developed is represented in figure 4.10.

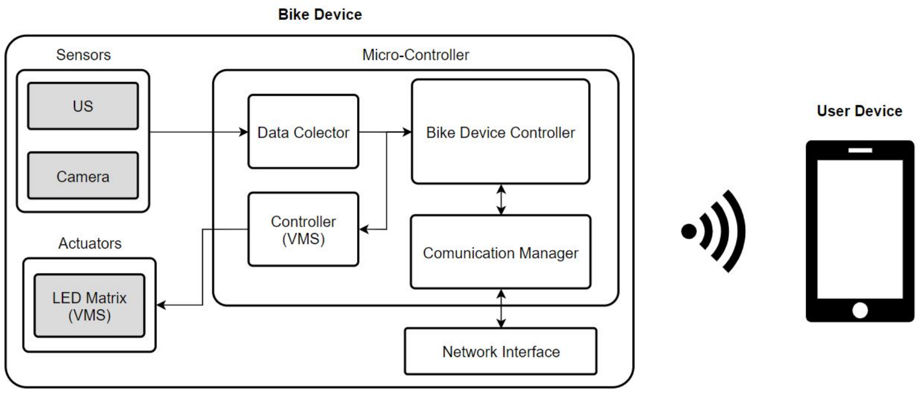


Figure 4.10: System simplified Architecture.

Comparing to the architecture originally proposed, there are two main differences that needs to be considered. First, the bike device was autonomously developed and neither the user device nor the remote server were implemented. So, the communication with external devices comprises only the minimum set of functionalities to proof the concept (storage data at an external device). Second, no radar was included in the bike device system.

4.3.3 Bike device system - components and interactions

The bike device system is structured as depicted in figure 4.11, using a similar approach to the one that was proposed during the design of the architecture.

4.3.3.A Bike device controller

The Bike device controller component is responsible for controlling the other components. The system will be constantly fetching data from the Data collector while sending it to the Communication manager. Besides the Controller will send send the information to the VMS controller when it is needed to change the displayed message. It is the controller's function to control this tasks, to guarantee the correct system's behaviour and initialize and terminate the other components' operation (figure 4.11).

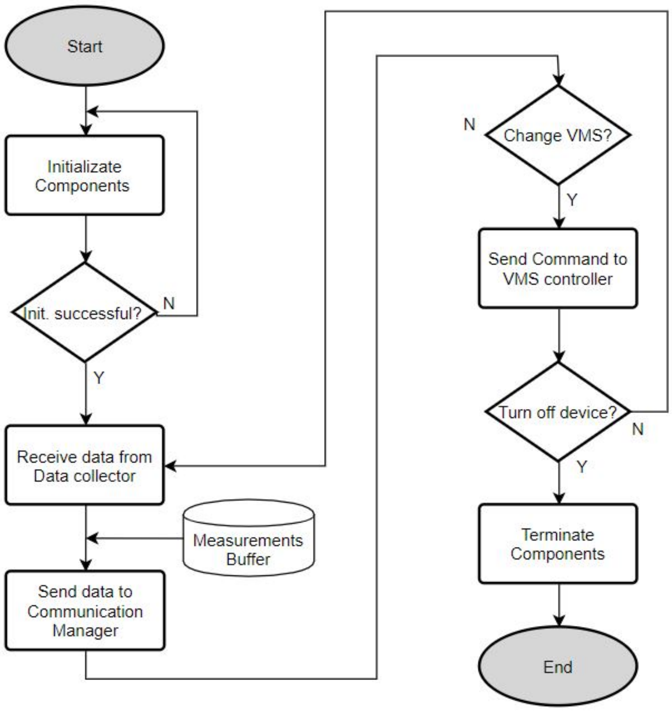


Figure 4.11: Device controller Flowchart.

4.3.3.B Data collector

The Data collector is responsible for the management of the data acquisition from the sensors. This component consists of different integrated blocks with different functions such as conditioning the obtained analog signal, converting it to a digital format to be then processed, analysed, stored and displayed.

In this project, sensors measurements are stored in the buffer in order to be read by the Device controller. We used a round robin cycle to retrieve data from each one of the sensors, during each time interval.

Figure 4.12 represents the flowchart of the data collection procedure.

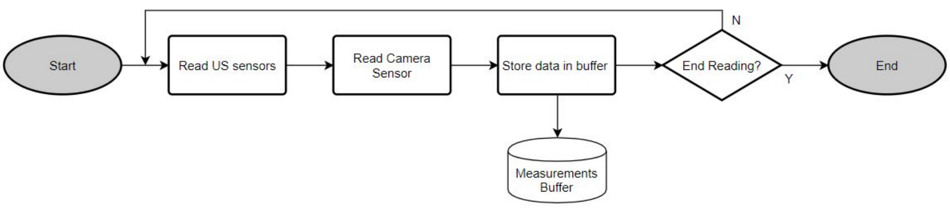


Figure 4.12: Data collector Flowchart.

4.3.3.C Controller (VMS)

This component is responsible for controlling the VMS and the displayed messages. The messages are predefined for the different actions such as when the bicycle reduces the speed and when the cyclist changes direction. In figure 4.13 and 4.14 it is possible to observe two different messages that are possible to display.

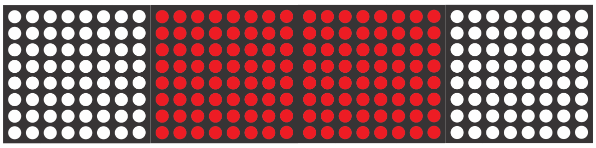


Figure 4.13: VMS - Break Message.

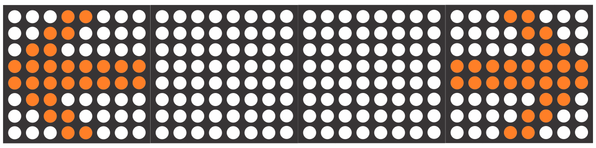


Figure 4.14: VMS - Direction change.

The flowchart of the VMS controller is depicted in figure 4.15.

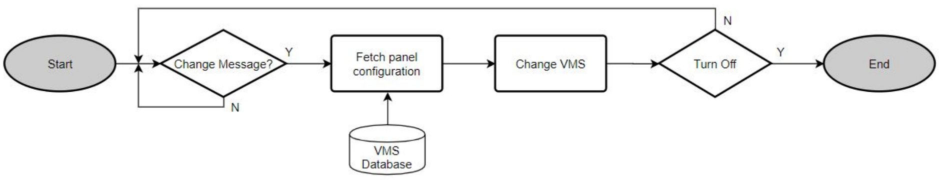


Figure 4.15: VMS Controller Flowchart.

4.3.3.D Communication Manager

The Communication Manager component is responsible for managing the communication between the bike device and other devices, such as the user's smartphone.

Figure 4.16 depicts the flowchart of the communication between the device and the smartphone.

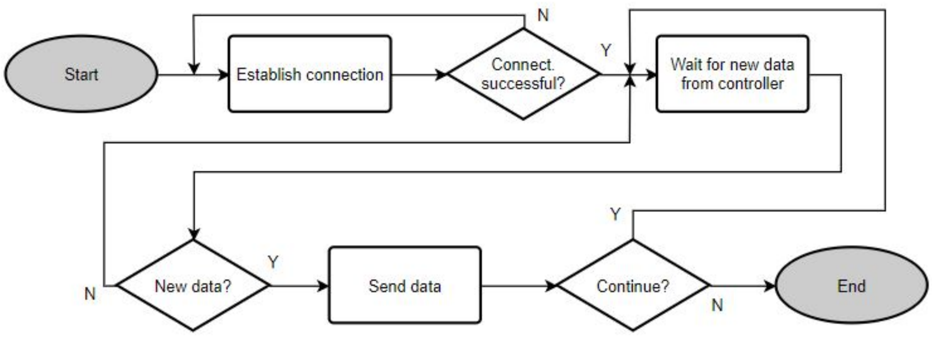


Figure 4.16: Communication Manager Flowchart.

4.3.4 Bike device system - smartphone interaction

To test the system and demonstrate its results it is necessary to implement and use a simple application to run on the smartphone. To use the BT it will be used an application that will be used as command line in a first stage. For the final system it will be developed a client that receives the data from the RPi through Wi-Fi.

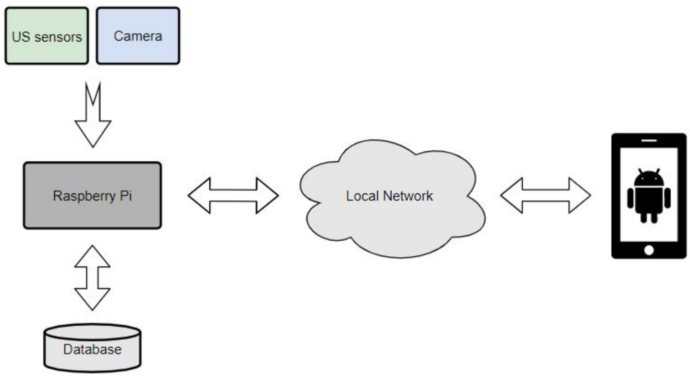


Figure 4.17: Communication topology.

As stated before, the python implementation for BT and BLE communication for uses BlueZ through a library. The BT communication programming in Python follows a socket model. The communications between the devices is done through Radio Frequency Communication (RFCOMM) socket, a protocol which provides serial port emulation.

Figure 4.17 represents the interaction between the bike device system and the smartphone as a complete system.

It was developed a Hypertext Transfer Protocol (HTTP) web server that listens to a request on a Transmission Control Protocol (TCP) socket address, which is RPi Internet Protocol (IP) address and the port number. After receiving this request it sends back a response with a html file of the application.

4.4 3D Model

4.4.1 Design options

To be used in a bicycle the bike device system must be assembled and included in a closed-box.

Type of boxes: Two main options are available: use an of-the-shelve box and adapted it to include the peripherals, visible at the adequate places, or design a specific 3D model.

3D printing or as it is also known, additive manufacturing, is a process of making three dimensional solid objects from a digital file, generated from a Computer Aided Design (CAD) software. In an additive process an object is created by laying down successive layers of material until the object is created. Each of these layers can be seen as a thinly sliced cross-section of the object. Hence, the object design can be targeted to its purpose. In our case, this is very relevant, due to the need of using US sensors in different positions, and a VMS message board.

We decided to 3D printing our box.

CAD software: The 3D printer is feed with a CAD design that describes the object to be prototype. The used CAD software was Onshape[2], which is available on the Internet and is free.

4.4.2 Box production

After choosing the components and designing the circuit it was developed a 3D-geometrical model of a case for the device, in order to assemble all the components and mount in the bicycle.

There were created several iterations that resulted in the final 3D model that was then manufactured by 3D printing. The used printer is a printer of my own, a Creality 3D® Ender-3 V2.

Figure 4.18 represents the 3D model of the box that will be use to deploy our bike device system.

The details of the components are illustrated in figure 4.19 where it is possible to observe the device drawing and its size.

[2]https://www.onshape.com/

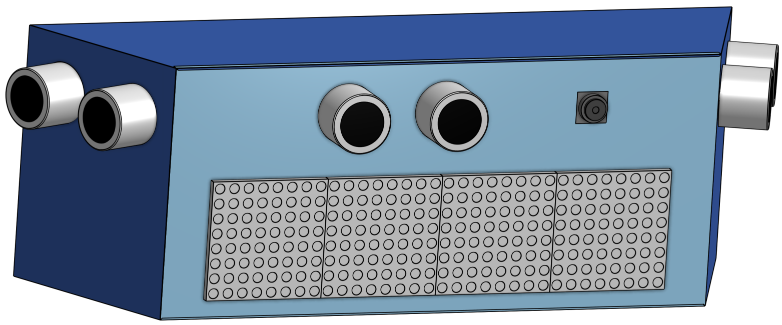


Figure 4.18: Bike device 3D Model.

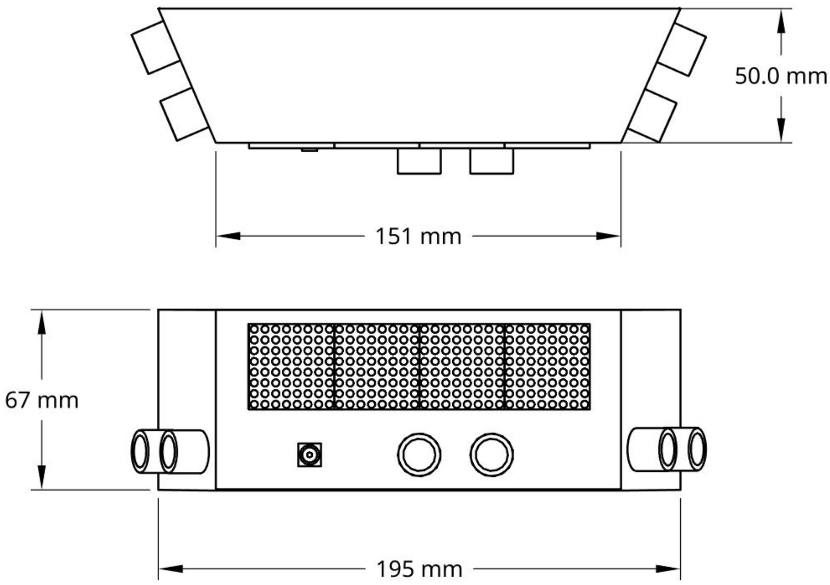


Figure 4.19: Bike device drawing.

4.5 Prototype system

A prototype of our system was created and packed into our 3D box. This section details it.

4.5.1 Board prototype

It was developed a prototype board after the realization of the tests presented in chapter 5. The goal of this board is to optimize all the existent connections between the RPi and the other components and have less wires and a reduced size. This board connects directly to the RPi GPIO as it is possible to observe in figure 4.20. Besides the components such as resistors, capacitors and LED the board contains the connectors to connect the US sensors and the VMS. It is important to mention that it was not developed a Printed Circuit Board (PCB) due to the circumstances of the year 2020 and the limitation to use the laboratories and necessary facilities.

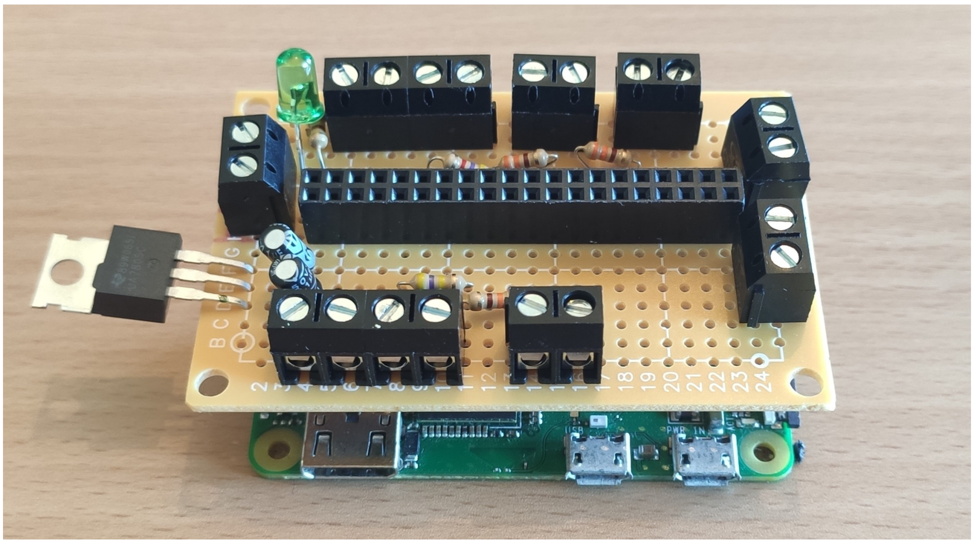


Figure 4.20: Prototype Board connected to RPi.

After that, a complete system was developed, as illustrated in figure 4.21. It is possible to observe the different components and the connections to the developed board and consequently to the RPi.

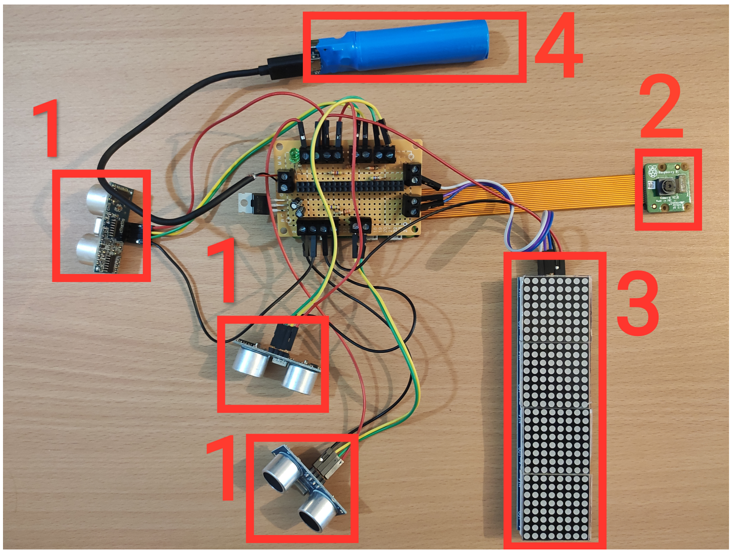


Figure 4.21: Prototype complete system (1 - US Sensors; 2 - Camera; 3 - VMS; 4 - Battery).

4.5.2 3D model prototype

The system was packed in the 3D box, and the result achieve is illustrated in figure 4.22.

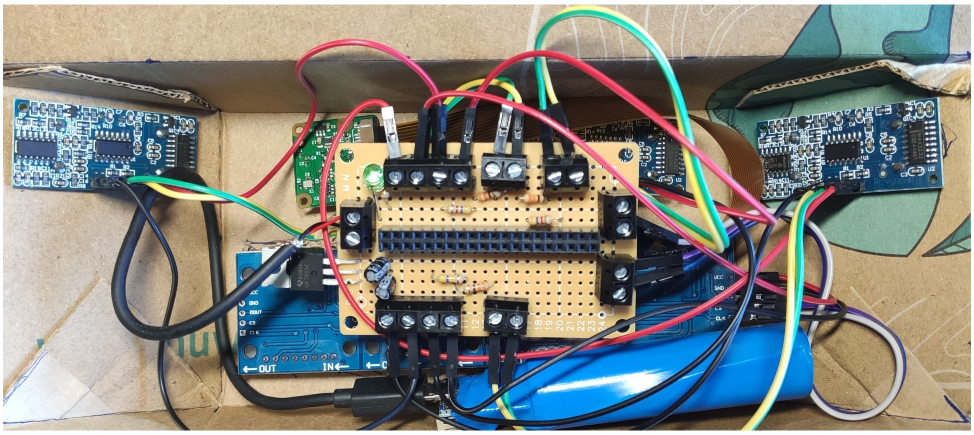


Figure 4.22: Complete system's prototype (Inside the box).

Note that, the device is mounted using an universal adapter as it is possible to see in figure 5.9.

4.6 Synthesis and discussion

There were different challenges while designing the system during the chapter. Evaluating the initial architecture it is possible to observe that it was not implemented the RADAR sensor due to its complexity and limited time. After developing the hardware, it was developed the software that will run in the bicycle device. There were firstly developed different modules with the individual functions such as reading US sensors or the camera module. This was useful as well for the test phase to test the different functions. In the final stage it was implemented the complete software that achieves all the desired functions, as it was explained in the chapter.

After the system's development, it is ready to be tested, not only its capabilities but also its behavior in a real simulation. Those tests will be demonstrated in the next chapter (5).

5

System Validation

Contents

Testing and Results

In this section the tests that were done with the complete system are going to be described. One of the main goals is to verify the system behaviour in a practical scenario as well as if the requirements established in chapter 3 were met. It is important to characterize the behaviour of the system in a moving bicycle and how the different variables and environment affect the capabilities of the system.

5.1 System Characterization

This test phase was conducted to understand the system's capabilities for detecting vehicles and help the cyclist to have a safer ride.

5.1.1 Prototype development phases and validation

The first stage was to test the circuit on the breadboard prototype, consisting of the elements from the circuit design (figure 4.8), as is possible to observe in figure 5.1. This prototype was used to test the basic functions such as the sensor's behavior or to estimate the power consumption of the system.

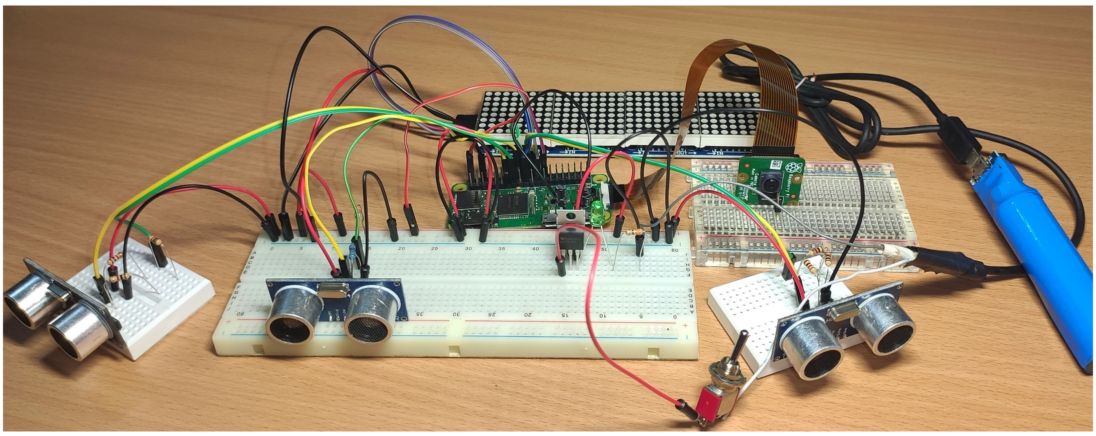


Figure 5.1: Breadboard Prototype.

This stage is important because it allows to make changes to the circuit by replacing components or jumper wires before make a prototype board and test on a real bicycle.

After testing the system capabilities in the laboratory it was conceived a cardboard box, with the same shape as the 3D model developed before (figure 4.18) and mount in the rear of the bicycle, under the seat, which can be seen in figure 5.2. After undertake all the tests it is possible to print the model in a 3D printer afterwards.

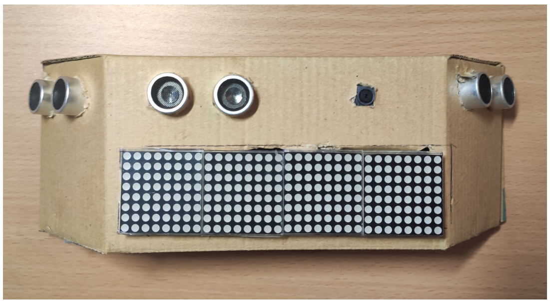


Figure 5.2: Cardboard box with the prototype.

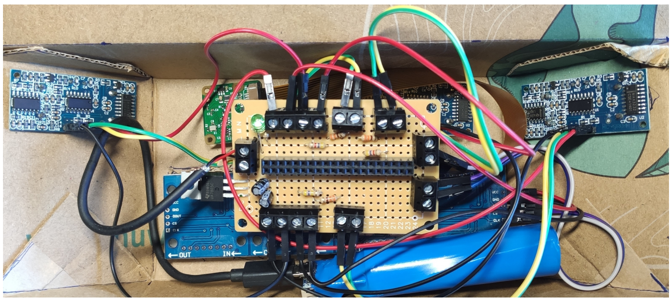


Figure 5.3: Prototype's inside view.

In figure 5.3 it is represented the interior of the prototype where there is all the hardware developed before.

5.1.2 Power consumption

An important aspect of the device is the power consumption. An accurate estimation of the RPi's power consumption can be obtained by knowing the required current drawn by the system, which is also important to estimate the required battery capacity.

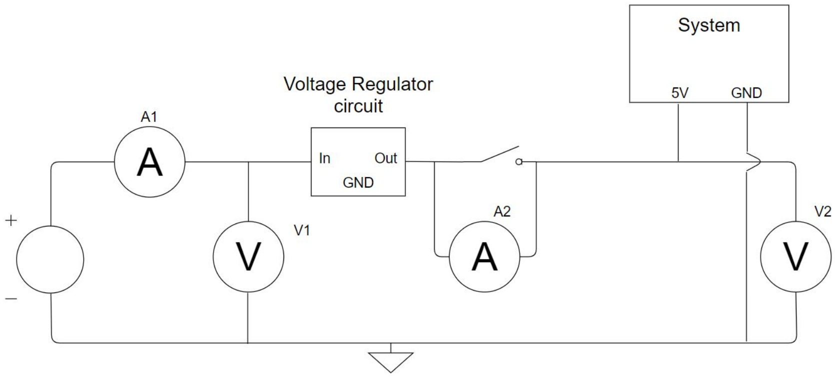


Figure 5.4: Connection scheme for power requirements testing.

It is possible to reduce the power consumption by knowing the power model and optimizing the software running on the platform. In [45] it is developed a power model that measures the power consumption of the microcontroller using an external power meter, which is one possible approach. Other approach is measuring using voltmeters and ammeters placed as in figure 5.4. The system was tested with the RPi Central Process Unit (CPU) idle, as well as in other utilisation states, such as sending data using a wi-fi or BLE connection. The obtained results are summarized in the table 5.1.

It is possible to verify that the the voltage regulator's output is at a stable 5V, regardless of the load and supply voltage. With this results it is possible to conclude that a battery with 5000 mah, and 3.7V is enough for an estimated period of 12 hours in the full system mode.

Function	Power usage
Idle (no sensors)	80 mA (0.4 W)
US sensor	15 mA (0.075 W)
Camera	230 mA (1.15 W)
Reading sensors	280 mA (1.4 W)
Wi-fi communication	120 mA (0.6 W)
BT communication	35 mA (0.175 W)
Full System	400 mA (2 W)

Table 5.1: System power usage (by function).

5.1.3 Distance Measurement

It was tested the accuracy of the sensor readings by comparing the values obtained from the sensor with the actual distance. It was used a measuring tape to know the exact distance and a small portable surface to reflect the sound waves between the different known distances (figure 5.5). The obtained values can be observed in table 5.2. For each distance there were made 50 measures, the obtained result was the average of those 50 values. It is possible to calculate the absolute error using the formula 5.1.

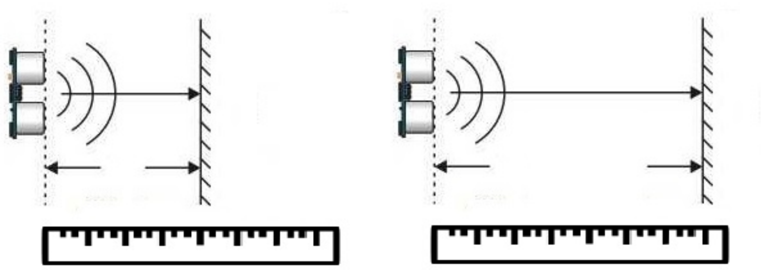


Figure 5.5: Distance measurement accuracy test.

Real distance (m)	Sensor measurement (m)	Accuracy (A_n)
0.50	0.49	98%
1.00	1.00	100%
1.50	1.51	99.3%
2.00	2.00	100%
2.50	2.48	99.2%
3.00	3.01	99.7%
3.50	3.50	100%
4.00	3.99	99.8%

Table 5.2: Comparison of HC-SR04 US sensor data and real distance.

$$e = |X_n - Y_n| \quad (5.1)$$

In 5.1, e is the absolute error, X_n the expected value and Y_n the measured value. The accuracy, which is the degree of closeness of the measurement to the true value, can then be obtained by using formula 5.2.

$$A_n = |1 - \frac{e}{X_n}| \quad (5.2)$$

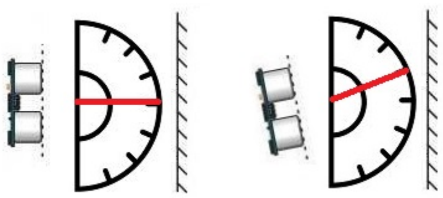


Figure 5.6: Maximum angle test.

To determine the maximum angle between the direction of the emitted sound waves and the object's surface it was registered the angle when the obtained values were no longer correct and valid as it is demonstrated in figure 5.6. It was concluded that the maximum angle is 15º.

It is possible to conclude with the results that the results obtained from the US's reading are reliable and can be used to inform the rider about the presence of vehicles in the rear.

5.1.4 Data Transfer

For the communications it was tested two different scenarios, using BT and using Wi-Fi. Although BT's and BLE are the best options to send data from the sensors, mainly because of the reduced power consumption, they are not a good option to stream video from the camera. Therefore it was tested an approach using Wi-Fi by implementing a WLAN with the smartphone and the bicycle device.

For the BT test it was used a BT terminal Android application which supports RFCOMM protocol. Figure 5.7 demonstrates a print of the Smartphone screen running the app while receiving data from RPi regarding the a US sensor.

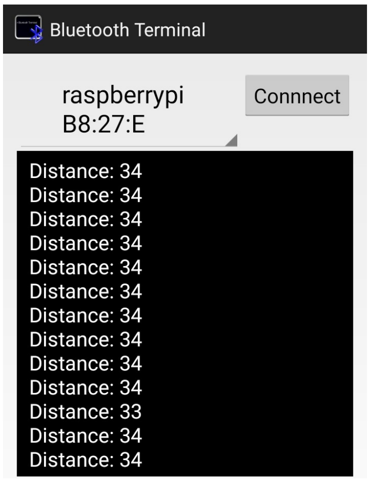


Figure 5.7: US sensors data reception (in cm) using a BT terminal App (Android device).

Regarding the data stream using a HTTP web server, it was developed using Websocket protocol which enables a full-duplex communication channel. Figure 5.8 demonstrates the interaction between the smartphone and the RPi

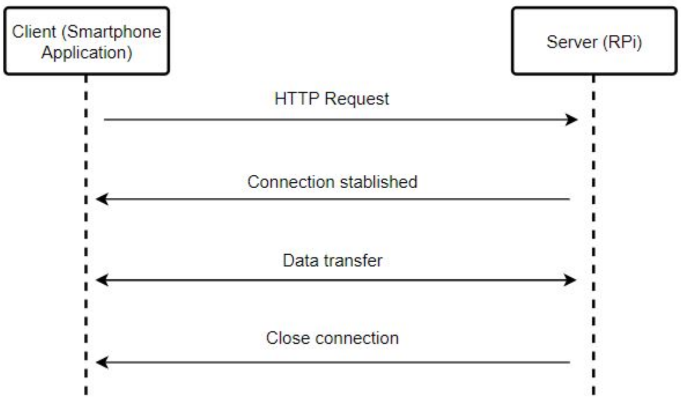


Figure 5.8: Interaction between the client (Smartphone) and the server (RPi).

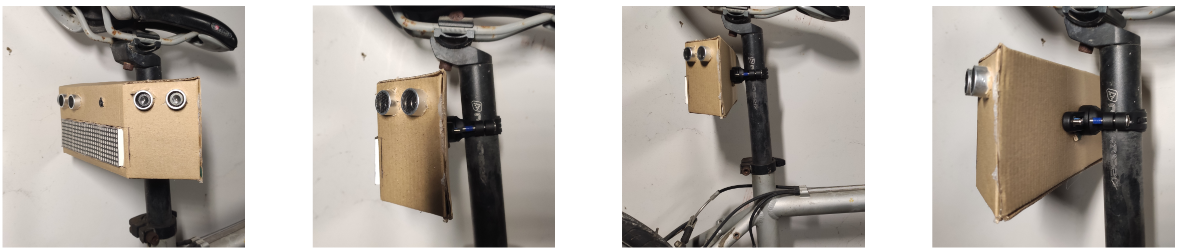
Although BT reliability there was the need to use wi-fi in order to stream video from the camera, due to its increased bandwidth, bit-rate and low latency. After the tests it was decided to use a solution previously presented (figure 4.17) to the final system and the field tests.

5.2 Field Test and Results

In this section it was performed a different number of tests in order to evaluate the prototype in a real life situation. The goals were to observe the system behavior on the different situations such as when the bicycle is being overtaken by a car or when it passes by a parked car.

5.2.1 Test scenario

The data was acquired by the prototype device during several rides with the bicycle on a circuit with the necessary movement to test the capabilities. The prototype was mounted in the bicycle as it is possible to visualize in figure 5.9.



(a) (b) (c) (d)

Figure 5.9: Device mounted in the bicycle.

Using the information retrieved from the rider's Smartphone GPS using Strava application [1], it is possible to track the bike movement and define its route. In figure 5.10 it is possible to visualize the route of one of many tests that were conducted.

5.2.2 Test results - Rear view - camera

This section presents the results of the camera's use as a rear view display. This functionality was founded important due to the interviews conducted in a beginning phase, where it was a major concern not having the information of the rear view. Although the US sensors give information, the option to watch the image as well it is important for some users because it gives a feeling of increased safety and control.

[1] Strava App: https://www.strava.com

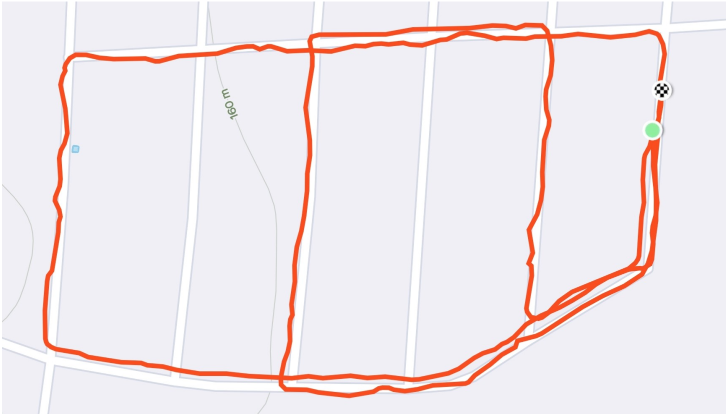


Figure 5.10: Field Test road map.

In figure 5.11 it is possible to observe the dashboard on the smartphone in two different situations, on the left when there is a car in the rear and on the right when there was no movement on the street, only vehicles that were parked on the side of the road. The image that is streamed from the device to the smartphone has a reasonable quality and has an acceptable delay that is usually inferior to one second. The dashboard includes the camera view in the centre and the three US sensors readings.

Figure 5.11: Field Test (Smartphone screen).

5.2.3 Test results- obstacle detection - US sensors

In figure 5.12 it is possible to see the data collected from the sensors when the rider, at the speed of 10 km/h was overtaken by its left size. From the results we can note that in a first phase, the center sensor is the only for the three that is detecting an object. Since the rider was riding at a relatively reduced speed the car stands just for a few moments in the back of the bicycle and when it was safe it started the overtake, as it is possible to observe when the left sensors starts to detect the vehicle while the one in the center continues to detect. There is a certain moment where the vehicle is no longer detected by the center sensor but only by the left sensor. The sensor stops detecting the vehicle when it is next to the bicycle and the angle between the propagation direction and the car surface is superior than the maximum angle detectable.

In figure 5.13 it is represented the data collected from the sensors when the rider passes by a parked car on the right side of the road ate 10 km/h. It demonstrates that the right US sensor is the only that detects the object, The sensors starts detecting the object when the angle between the propagation direction and the car surface is enough to reflect the sound waves. As the time passes by the distance between the bicycle and the vehicle increases as the rider continues the movement and the car is still in the same position.

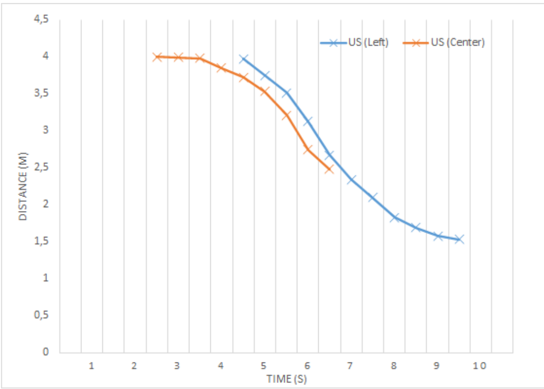


Figure 5.12: Sensor data when overtaken.

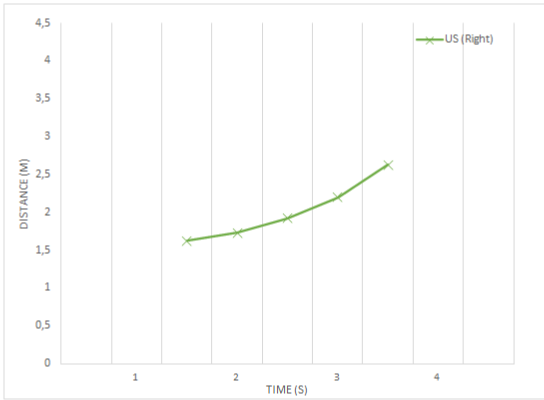


Figure 5.13: Sensor data when passing by parked car.

Furthermore it is possible to observe using the data from the experiments that the prototype can obtain the distance from a vehicle in the rear of the bicycle when it is closer that 4 meters, as it was concluded previously when the sensors where tested in the laboratory.

5.3 Synthesis and discussion

After the different experiences, the system demonstrates a good accuracy and a good performance, not only in the laboratory but also in the field tests. In terms of autonomy the battery that was estimated before it is sufficient for this application, making it possible to run the system for several hours without recharging it. In terms of the the device's box and how it is mounted, the tests showed that it is a robust solution that maintains the stability the system needs to perform with an acceptable performance.

In conclusion it possible to perceive that this basic version of the proposed architecture works properly and that fulfills its primary goal, which is giving information from the rear of the bicycle and in a certain way, increasing the rider's perspective of safety.

6

Conclusions

Conclusions

For many around the globe, the future of transportation was invented more than 100 years ago, has two wheels and handlebars, the bicycle. Of course that the technologies used nowadays are slightly different and that there is a lot of work that is being done in the field, with the use of different kinds of automation and processes, as it was studied and demonstrated in chapter 2. This Thesis aimed to continue the work in this field.

In this thesis it was developed a system to be installed in a bicycle that collects data from different sensors in order to give to the rider more information from the rear angles. The main goal was to increase the perception of safety and increase the use of the bicycle in roads that are common to every type of vehicle. To do that the system architecture was designed in 3 and had the goal to apply a full system, from the device to implement on the bicycle, an application for the smartphone to serve as the human-machine interface and a remote server where the data would be stored. Due to all limitations that this year of 2020 had and the complexity of the presented solution, the main goal was to develop a device to be installed in the bicycle capable of collecting the data and achieve the primary goals of the project and demonstrate them with a simple application on the smartphone as proof of concept.

The device is composed by a controller (RPi), a camera, US sensors, a VMS and a power supply as the main components. The RPi was chosen not only due to its processing capabilities but also to the in-built communications capabilities. The other components were chosen due to being the best options do built the prototype, in terms of performance and price.

After designing the circuit it was made a prototype on a breadboard in order to test the system's basic functions and to estimate the power consumption. The communication between the device and the smartphone was an important aspect of the project. In a first phase the data from the sensors was sent using BT but due to the necessity of streaming video it was chosen sending data using Wi-Fi, both capabilities available in the RPi. After the results validation it was made a prototype board in order to test on a bicycle in a real life situation. The device had a good performance in the tests, having accurate results and a good responsiveness. Therefore the results of the presented work in this Thesis demonstrate that it is possible to design and implement a low-coast device to increase the cyclists safety, by giving them more information from the angles without visibility.

Future Work

As it was stated before due to the limitations it was developed a simple version of the proposed architecture, which means that there is still work that can be done to improve this project.

In terms of user interface, there is the need to study which is the best approach, if having the smartphone is the best option abailable or if there is other methods. In case of continuing using the smartphone, it is necessary develop an Android application in order to improve the user experience, instead of using a generic browser.

In terms of hardware it can be developed a dedicated PCB instead of using a generic prototype board where the lanes are done by hand or using jumper wires. There is some work that can be done in order to add more sensors, such as the RADAR that would extend the range of the device. To increase the system capabilities there are other sensors that can be included as well to give more information about the ride to the rider, such was humidity and CO sensors.

It would be also necessary to develop the project and study more the final approach or other possible approach regarding the possible effects that can affect the system's behaviour, such as the Doppler effect.

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Appendix

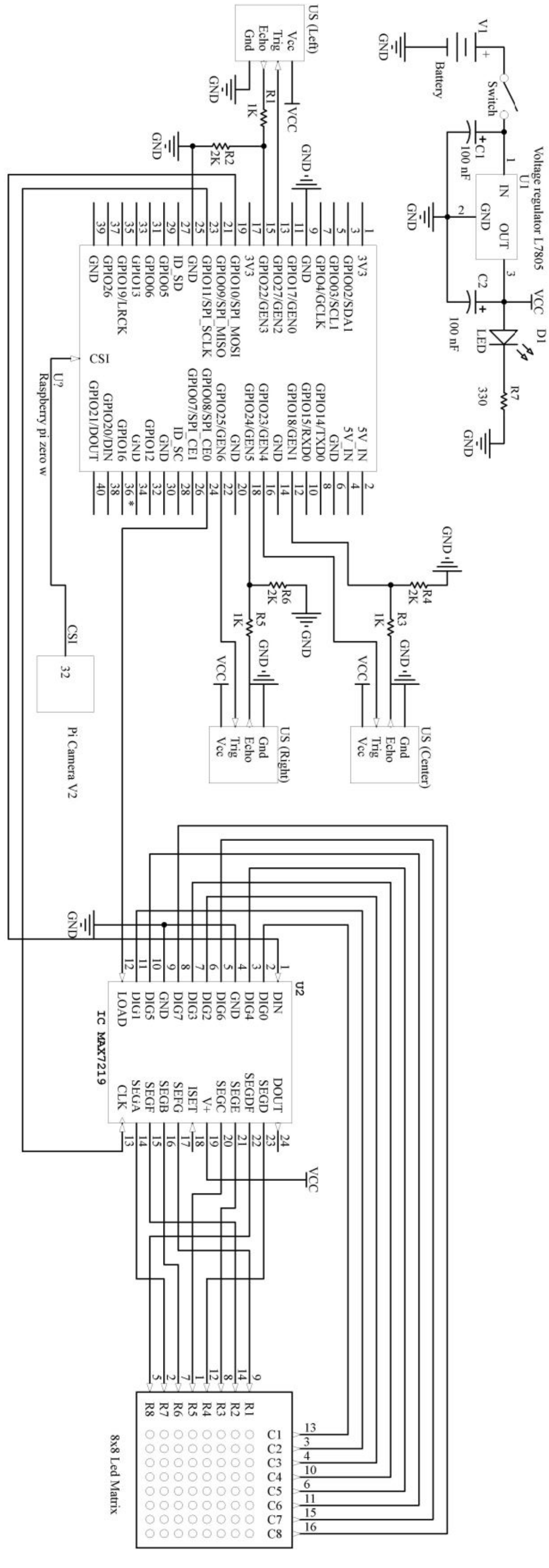

Figure A.1: System circuit