

Real-time Bicycle Management System

André Rodrigues Lopes

Instituto Superior Tecnico

Lisbon, Portugal

andre.rodrigues.lopes@tecnico.ulisboa.pt

Abstract—This project intends to develop 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.

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 security and comfort and at the same time encourage others to use it.

Keywords—Urban Mobility, Road Safety, Bicycle, Embedded System, Sensors;

I. INTRODUCTION

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.

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

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.

II. STATE OF THE ART

A. 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 [3].

1) *Time-of-Flight (TOF)*: 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 1 illustrates the TOF principle previously described.

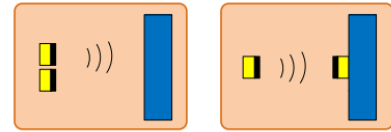


Fig. 1. Time-of-flight "round-trip" method (left) and "one-way" method (right). [4]

2) *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 1.

$$R = b \sin(\alpha_{left}) \sin(\alpha_{right}) / \sin(\alpha_{right} - \alpha_{left}), \quad (1)$$

3) *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.

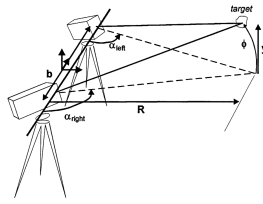


Fig. 2. Triangulation method. [5]

B. Sensor types

1) *Ultrasound (US)*: 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 [6]. This kind of sensors measures the distance to an object by using sound waves. The principle is based in the method. 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 [7]. US sensors have usually a good response to perturbations such as the non existence of light. One of the advantages related with the cost when compared with other technologies.

2) *Infra-red (IR)*: The 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 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 [8]. It usually offers a fast response and are usually associated to lower costs, compared with other types of sensors. The disadvantages are associated with their non-linearity in terms of behaviour, their dependence on the environment.

3) *RAdio Detection And Ranging (RADAR)*: RADAR 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 as presented in [9] [10]. 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. 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.

4) *LIght Detection And Ranging (LIDAR)*: 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. Such as

RADAR, it is able to work properly by night, however its working behaviour is affected by adverse conditions such as rain and fog. The high cost of this kind of sensors is also an important factor.

5) *Stereo Vision*: This technique is used to build 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. 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, such as in [11]. One of the main advantages is the possibility to give information about the objects in the rear angle, but also give the real live image. One of the main disadvantages is related with the cost.

C. Multi-sensors systems

Self-driving vehicles have different types of objects to track and to identify. In order to have a solution 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.

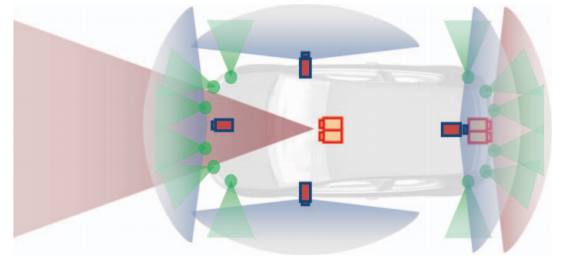


Fig. 3. System sensors layout. [12]

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, that have different characteristics and can complete each other, as it is possible to observe in [13]. In figure 3 it is possible to observe a vehicle with such as a complete system with different types of sensors.

D. 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. One of the major concern is related with power consumption, as well to possible data security threats and lower data rates.

1) *BLE - IEEE 802.15.4 standard*: Bluetooth Low Energy (BLE) is a Bluetooth (BT) version specified in the version 4.0 with low energy consumption. This technology is intended to be used for short-range communication with the special concern in the energy consumption [14].

Similar to the classic BT, the BLE protocol stack, figure 4 is mainly composed by two main parts, the controller and the host. In the controller there are the two lowest layers, the Physical that takes care of transmitting and receiving bits, and the link layer that provides medium access, connection establishment, error control, and flow control.

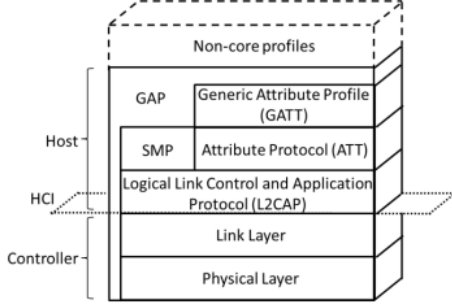


Fig. 4. BLE protocol stack. [15]

BLE also supports multiple network topology, 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 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 ISM. All the physical channels use a GFSK modulation, which is simple to implement and allows a reduced peak power consumption. In terms of saving energy, there are mechanisms that allow and maximize it. The usual energy consumption goes from 1mW to 50 mW, with a maximum peak current consumption of 15 mA, depending on the used mode.

2) *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 WLAN. It defines the MAC procedures for accessing the physical medium, which can be IR or radio frequency 802.11 device [16].

A Wi-Fi WLAN is based on a cellular architecture, where each cell is called a BSS. The simplest network configuration is the independent BSS, which implements an ad hoc network topology. Alternatively, an infrastructure BSS may be part of a wider network, called extended service set (ESS).

Usually Wi-Fi is used in small distances applications but some can go up to 100 m. 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. A Wi-Fi device typically requires between 100–350 mA.

III. SYSTEM ARCHITECTURE

The entire system comprises three components: the Bike device and the End-user device as depicted in figure 5.

The bike device system is installed in the 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.

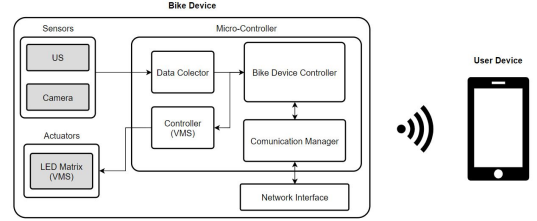


Fig. 5. System Architecture.

1) *Bike device*: The bike device it must be a portable and easily installed in the rear part of the bike under the seat. It 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. 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 and a camera. Information retrieved from sensors is gathered by the Data collector.

Actuators are 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.

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 GPS, 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.

IV. SYSTEM DESIGN - HARDWARE

A. 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 Raspberry Pi (RPi) Zero W due to its reduced size, which is ideal for the system, to connectivity and processing capabilities and also the reduced price.

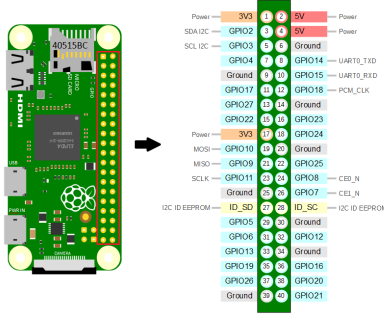


Fig. 6. Raspberry Pi Zero W GPIO pinout.

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 Raspberry Pi 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 General Purpose Output-Input 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. It is possible the communication with other devices using different communication protocols such as I2C, SPI, serial communication using UART and CSI (camera).

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

B. Sensor - Ultra-Sound

The ultrasonic sensor used is the Ultrasonic Ranging module HC-SR04 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 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.

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

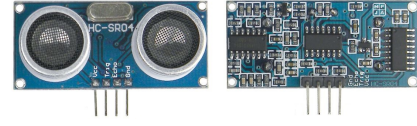


Fig. 7. US sensor module HC-SR04.

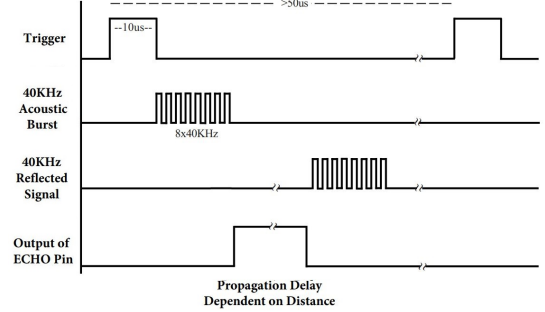


Fig. 8. Operation principle - US sensor module HC-SR04.

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 equation.

$$Distance = Speed \times Time, \quad (2)$$

If the sent pulses are not reflected back, the Echo signal will timeout after 38 milliseconds and return low.

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 big enough surface to reflect the waves. Other limitation is related with the angle between the direction of the emitted waves and the surface.

C. Sensor - Camera

It was chosen the RPi camera module that has a Sony IMX219 8-megapixel back-illuminated 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 its small size, of 25 mm x 23 mm x 9 mm, and also due to the fact that is a low cost camera sensor.

Image Processing: : RPi's 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.

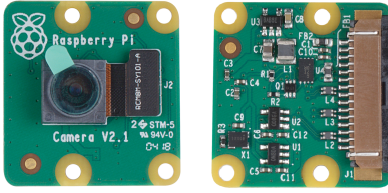


Fig. 9. Raspberry Pi Camera Module V2.1.

D. 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 10 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.

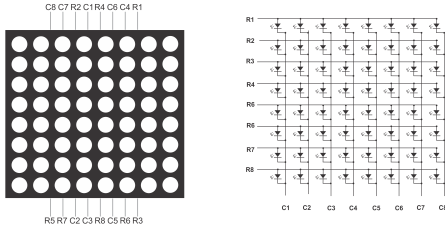


Fig. 10. 8X8 LED Matrix Display internal circuit diagram.

Due to the limited size of the GPIO, to control the panel efficiently it is necessary to have an interface between the LED matrix and the RPi, using MAX7219 IC, a common-cathode display driver (image 11).

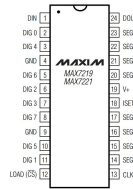


Fig. 11. MAX7219 IC top view. [17]

Each one of the four 8x8 matrix will have one of this IC with serial input and parallel output that connects the controller to the display.

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.

E. Circuit design

Figure 12 describes the schematic of the bike device system. It 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.

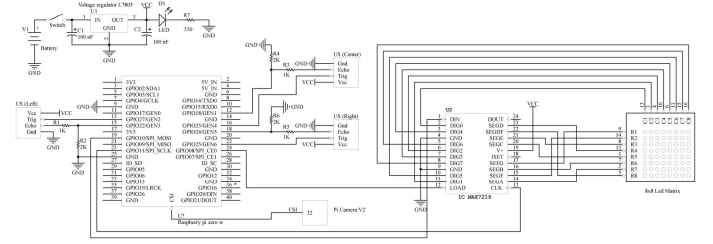


Fig. 12. System circuit.

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, it is then needed to use a voltage divider circuit.

$$V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2} \quad (3)$$

Using 3 the chosen resistors values are 1KΩ and 2KΩ.

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.

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.

V. SYSTEM DESIGN - SOFTWARE

A. 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 Real Time or version of a general purpose OS, specially optimized for use with the RPi. We decided to use the last approach because 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) ¹, 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.

¹Raspberry Pi OS image: <https://www.raspberrypi.org/software/operating-systems/>

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

Communication: The communication between the bike device and the external components relies on Bluetooth or (eventually Wi-Fi). Bluetooth has its own protocol stack and requires special software libraries to operate. It was used BlueZ, an official Linux BT protocol stack in order to provide support for the BT layers and protocols.

B. Bike device system - components and interactions

The bike device system is structured as depicted in figure 13, using a similar approach to the one that was proposed during the design of the architecture.

1) *Bike device controller:* The Bike device controller component is responsible for controlling the other components.

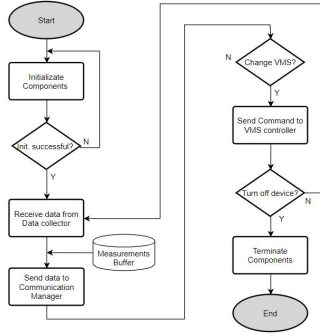


Fig. 13. Device controller Flowchart.

The system will be constantly fetching data from the Data collector while sending it to the Communication manager. Besides the Controller will send the information to the VMS controller when it is needed to change the displayed message. It is the controller's function initialize and terminate the other components' operation (figure 13).

2) *Data collector:* The Data collector is responsible for the management of the data acquisition from the sensors. 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 14 represents the flowchart of the data collection procedure.

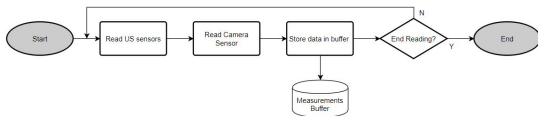


Fig. 14. Data collector Flowchart.

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, figure 15 and 16.



Fig. 15. VMS - Break Message.



Fig. 16. VMS - Direction change.

The flowchart of the VMS controller is depicted in figure 17.

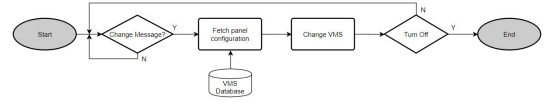


Fig. 17. VMS Controller Flowchart.

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.

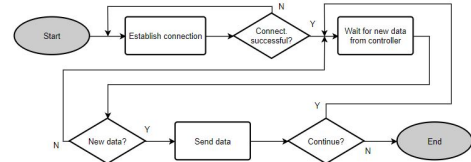


Fig. 18. Communication Manager Flowchart.

Figure 18 depicts the flowchart of the communication between the device and the smartphone.

E. Bike device system - smartphone interaction

To test the system and demonstrate its results it was implemented 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.

The BT communication programming in Python follows a RFCOMM socket model, a protocol which provides serial port emulation. Figure 19 represents the interaction between the bike device system and the smartphone as a complete system.

It was developed a HTTP web server that listens to a request on a TCP socket address, which is RPi IP address and the port

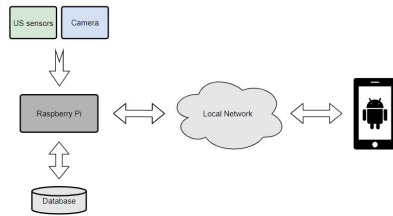


Fig. 19. Communication topology.

number. After receiving this request it sends back a response with a html file of the application.

VI. 3D MODEL

A. Design options

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

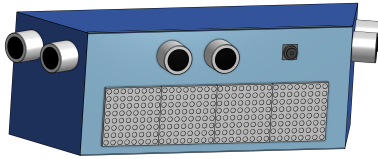


Fig. 20. Bike device 3D Model.

3D printing is a process of making three dimensional solid objects from a digital file, generated from a CAD software. The used CAD software to design the model was Onshape², which is available on the Internet and is free. Figure 20 represents the 3D model and 21 of it.

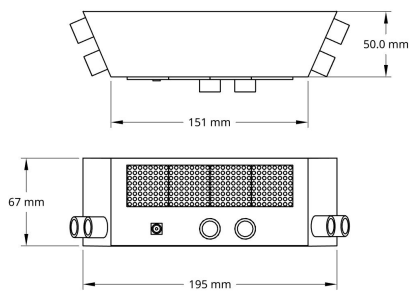


Fig. 21. Bike device drawing.

VII. PROTOTYPE SYSTEM

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

²<https://www.onshape.com/>

A. Board prototype

It was developed a prototype board after the realization of the tests presented in chapter ???. 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 22. Besides the components such as resistors, capacitors and LED the board contains the connectors to connect the US sensors and the VMS.

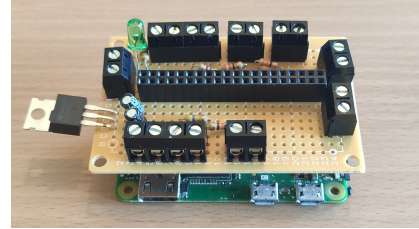


Fig. 22. Prototype Board connected to RPi.

In figure 23 it is possible to observe the different components and the connections to the developed board and consequently to the RPi.

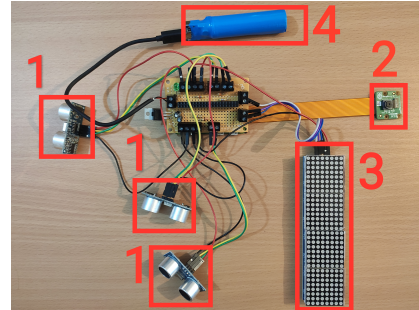


Fig. 23. Prototype complete system (1 - US Sensors; 2 - Camera; 3 - VMS; 4 - Battery).

B. 3D model prototype

The system was packed in the 3D box, and the result achieve is illustrated in figure 24.

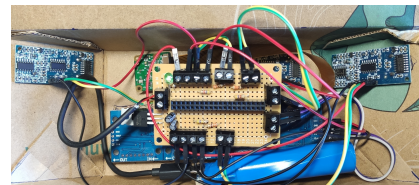


Fig. 24. Prototype complete system (Inside the box).

VIII. 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.

A. 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 12). This prototype was used to test the basic functions such as the sensor's behavior or to estimate the power consumption of the system.

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 20) and mount in the rear of the bicycle, under the seat, which can be seen in figure 25. After undertake all the tests it is possible to print the model in a 3D printer afterwards.

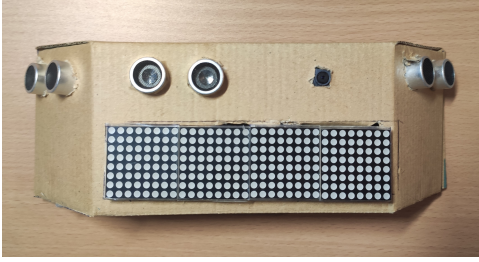


Fig. 25. Cardboard box with the prototype.

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

B. Power consumption

An important aspect of the device is the power consumption. An accurate estimation of the Raspberry Pi's power consumption can be obtained by knowing the required current drawn by the system (figure 26), which is also important to estimate the required battery capacity [18].

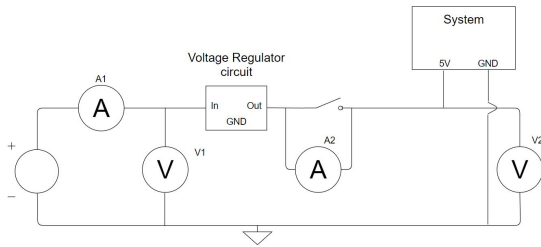


Fig. 26. Connection scheme for power requirements testing.

It is possible to reduce the power consumption by knowing the power model and optimizing the software running on the platform. The results are shown in I.

C. 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 27). The obtained values can be observed in table II. For each distance there were made 50 measures, the obtained result was the

Function	Power usage
Idle (no sensors)	0.4 W
US sensor	0.075 W
Camera	1.15 W
Reading sensors	1.4 W
Wi-fi communication	0.6 W
BT communication	0.175 W
Full System	2 W

TABLE I
SYSTEM POWER USAGE (BY FUNCTION).

average of those 50 values. It is possible to calculate the absolute error using the formula 4.

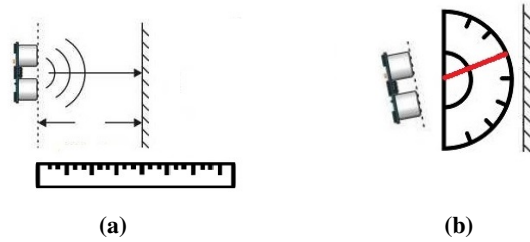


Fig. 27. US range and angle test.

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 II
HC-SR04 US DATA AND REAL DISTANCE.

$$e = |X_n - Y_n| \quad (4)$$

In 4, 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.

$$A_n = |1 - \frac{e}{X_n}| \quad (5)$$

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 27. It was concluded that the maximum angle is 15°.

D. 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, 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 28 demonstrates a print of the Smartphone screen running the app while receiving data from RPi regarding the a US sensor.

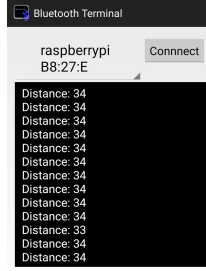


Fig. 28. US sensors data reception (cm) using a BT terminal App (Android).

Regarding the data stream using a HTTP web server, it was developed using Websocket protocol which enables a full-duplex communication channel. Figure 29 demonstrates the interaction between the smartphone and the RPi.

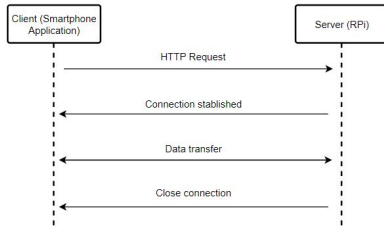


Fig. 29. Interaction between the client (Smartphone and the server (RPi)).

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 19) to the final system and the field tests.

IX. FIELD TEST AND RESULTS

There were 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.

A. 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 30.

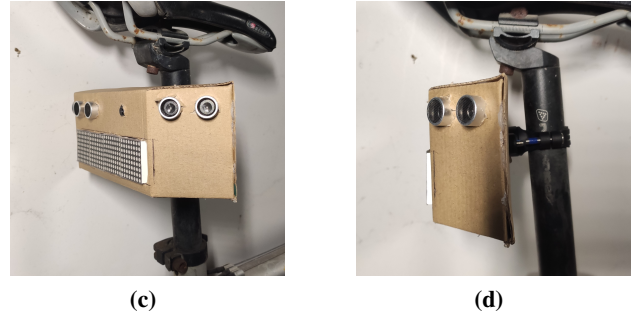


Fig. 30. Device mounted in the bicycle.

Using the information retrieved from the rider's Smartphone GPS using Strava application website ³, it is possible to track the bike movement and define its route (figure 31).

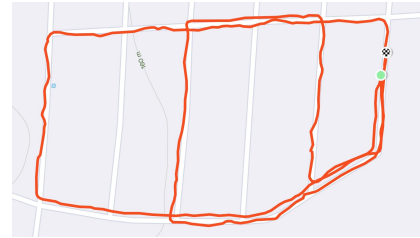


Fig. 31. Field Test road map.

B. Test results - Rear view - camera

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.

In figure 32 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. The dashboard includes the camera view in the centre and the three US sensors readings.



Fig. 32. Field Test (Smartphone screen).

C. Test results- obstacle detection - US sensors

In figure 33 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. Firstly the center sensor is the only that is detecting an object. At a certain moment the vehicle is no longer detected by the center sensor, 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

³Strava App: <https://www.strava.com>

the car surface is superior than the maximum angle detectable. In figure 34 it is represented the data collected from the sensors when the rider passes by a parked car on the right side of the road at 10 km/h. It demonstrates that the right US sensor is the only that detects the object. The sensors start detecting the object when the angle between the propagation direction and the car surface is enough to reflect the sound waves.

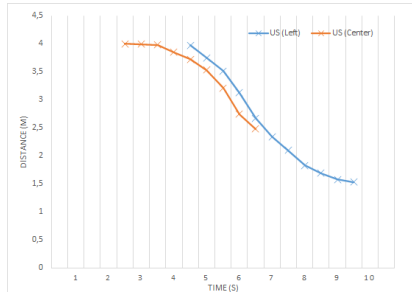


Fig. 33. Sensor data when overtaken.

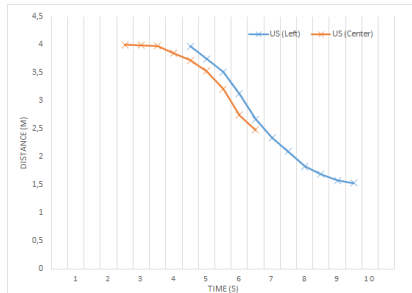


Fig. 34. Sensor data when overtaken.

X. CONCLUSIONS

In this project 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 the use of the bicycle in roads that are common to every type of vehicle. The developed system is composed by 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. It was tested in different scenarios and had a good performance, having accurate results and a good responsiveness. Therefore the results of the presented work demonstrate that it is possible to design and implement a low-cost device to increase the cyclists perception of safety.

Future Work

There is some work that can still be done. In terms of user interface, it can be developed a better solution to increase the user experience. In terms of hardware it can be developed a

dedicated PCB and more sensors, such as the RADAR can be added. To increase the system capabilities there are other sensors that can be included as well to give more information about the ride.

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