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ANALYSIS OF URBAN CYCLING MOBILITY USING IOT TECHNOLOGY

Ricardo Marin Israel
Guilherme Burda dos Santos
Isabela Antonietto de Abreu
Flávio Júnior Santiago Silva

José Viriato Coelho Vargas
Sustainable Energy Research & Development Center NPDEAS), Department of Mechanical Engineering – Federal University of Paraná (UFPR), CP 19011, 81531-980, Curitiba, PR, Brazil.
e-mails: ricardo.israel@ufpr.br , burdaguilherme04@gmail.com, isa.abreu022@gmail.com, flaviojrsantiago@gmail.com and jvcr@gmail.com.

André Bellin Mariano
Sustainable Energy Research & Development Center (NPDEAS), Department of Electrical Engineering – Federal University of Paraná (UFPR), CP 19011, 81531-980, Curitiba, PR, Brazil.
e-mail:andrebmariano@gmail.com.

Abstract. *In the context of the publication of the National Urban Mobility Policy in 2012 (law n. 12.587/2012 BRAZIL), Brazilian municipalities were challenged to develop an urban mobility plan aligned with the agenda of sustainable development. In short, the objective of this law is to encourage the use of collective and non-motorized transportation. Therefore, as a consequence of this movement, arises a need for gathering high-quality information to be used to create this plan, in the best way possible.*

Subsequently, this study aimed to use science and technology to collect environmental parameters such as temperature, humidity, sound, and cycling mobility metrics (the number of dangerous overtaking maneuvers experienced by cyclists). To achieve this, an IoT device was employed, connected to a smartphone app and installed on a bicycle to collect data. The IoT device was composed of a KY-038 (sound sensor), DHT22 (temperature and humidity sensor), HC-SR04 (ultrasonic sensor), Arduino Nano microcontroller, and HC-06 Bluetooth module. Notably, the HC-SR04 and DHT22 sensors provided consistent and accurate measurements, demonstrating their suitability for the task. While the results for the KY-038 sensor were inconclusive in terms of measurement patterns, it was included in the project to provide baseline data during cyclists' journeys.

To integrate the IoT device with the citizen, the Smart Mobility PRO application was created: an interface where the user interacts with the device, collecting the aforementioned parameters and also the GPS location of the smartphone. The equipment was used on several journeys to collect data on cycling mobility and other modes, demonstrating the feasibility of this proposed platform for studies of urban mobility. The results obtained with the above mentioned components were satisfactory, given the low variation of their results when subjected to tests and compared to other better-developed equipment for the function.

In summary, this law represents an important advance for sustainable urban planning and development in Brazil. Furthermore, for this reason, innovation was necessary, and the way to achieve it is by using science. A valuable tool for this purpose is the IoT device presented in this article.

Keywords: *Urban mobility plan, Science and technology, IoT device, Cycling mobility, Smart Mobility application.*

1. INTRODUCTION

In Brazil, in 2012, the guidelines of the National Urban Mobility Policy (PNMU) were published through Law 12.587, which aims to integrate different modes of transportation and improve the accessibility and mobility of people and goods within the municipal territory (BRAZIL, 2012).

In the context of improving the mobility of people in large urban centers, bicycles can offer a non-motorized transportation option, avoiding the use of individual motorized means (Rubim; Leitão, 2013). As a successful example, we can observe that the Dutch government defines, through a manual for bicycle-friendly infrastructure, five priority concepts for the road: coherence, direction, attractiveness, safety, and comfort (Crow, 1993).

As one of the study's objectives, the project seeks to develop a way to measure dangerous overtaking incidents that cyclists experience during their commutes. Furthermore, it has been observed that the environmental impact generated by

the rapid and disorganized growth of cities, combined with employment opportunities and improved quality of life provided by large national industries, contributes to the environmental degradation of urban areas (Gomes; Soares, 2004). High population density, asphalt paving, and industrial areas are some factors that contribute to this mentioned degradation (Lombardo, 1985). Such factors allow us to define parameters for data collection, such as thermal and acoustic levels, which are directly linked to environmental discomfort (Gomes; Soares, 2004).

The participation of society in data generation occurred in two ways: first, an IoT device attached to the bicycle collected information on temperature, humidity, sound, and the number of dangerous overtakings experienced by the cyclist. Second, users of both motorized and non-motorized modes of transportation were able to contribute GPS location data collected by their smartphones.

The increase in thermal and acoustic levels in urban areas is directly related to the degradation of the environment and the decrease in the quality of life for its population. Monitoring these parameters is essential for governments and citizens to seek solutions and alternative measures to address the degradation of living conditions. Therefore, with the collection of this data and in partnership with public agencies, it will be possible to intervene in these areas to improve them, such as planting trees for temperature and humidity control.

Considering specifically the movement of cyclists within large urban centers, compliance with the law by drivers is of paramount importance to ensure their safety. As previously mentioned, the enforcement of the law is flawed. In the context of the project, the quantification and qualification of dangerous overtakings will enable the creation of action plans aimed at promoting more safety for cyclists during their journeys. Furthermore, most studies on urban mobility safety focus on the architectural evaluation of roads or accident statistics, disregarding important aspects of cyclists' and drivers' behavior. The analysis of these data, collected in a distributed manner from various volunteers, presents a challenge, along with the need for real-time visualization of the parameters.

Therefore, the study presented in this article is based on urban cycling mobility and how to assist in the safety of cyclists and people who choose this mode of transportation in cities. After the publication of the National Urban Mobility Policy in 2012, Brazilian municipalities are committed to adopting urban planning policies that encourage the use of non-motorized and collective vehicles. From this point, this work, based on citizen science, aims to assist safe commuting for cyclists in the city through an IoT device that collects data such as temperature, humidity, sound, distance, and the number of overtakings experienced by cyclists due to motor vehicle traffic. By collecting data through this device and using an application to interpret and translate it, it will be possible to plan a safe and more favorable route for those who wish to travel by bicycle.

2. METHODOLOGY

The IoT device was developed based on the selection of components, the design and assembly of the printed circuit board (PCB), and the programming of the microcontroller. It was divided into the following phases: i) component selection, ii) hardware development, and iii) software development. After these three stages, it was necessary to create a protective case to attach the device to the bicycle.

2.1 Selections of components

For the design of the IoT device, it was necessary to select suitable, functional, and cost-effective sensors for the project. Initially, the development of the device used an Arduino Nano with an ATmega328 microcontroller, operating voltage of 5V, 14 digital ports, 8 analog ports with a maximum resolution of 10 bits, current on the In/Out pins of 40mA, and dimensions of 45 x 18mm. It is one of the smallest microcontrollers, easily programmable in the integrated development environment, the Arduino IDE. The programming language used is C and/or C++.

2.1.2 Sound sensor

To capture the sound from the environment and integrate it into the IoT device, the KY-038 model was used. This model consists of a capacitive microphone that captures sound waves and converts them into electrical energy. This process occurs due to the potential difference generated by the variation of capacitance between the metal plates that make up the microphone, with one of them being fixed and the other moving with the pressure of the sound waves (Santos; Oliveira, 2017).

2.1.3 Temperature and humidity sensor

For the selection of the humidity and temperature sensor, the DHT22 model was chosen. Communication occurs through the second pin, where temperature and humidity data are sent to the microcontroller through a sequence of forty bits, with a minimum spacing of two seconds between sequences. The first sixteen bits represent humidity, while the next sixteen bits represent temperature. In the case of temperatures below zero, the first bit of this sequence is set to 1 (one). After the bit sequence, the last eight bits are used for data integrity verification.

2.1.4 Ultrasonic sensor

The HC-SR04 ultrasonic sensor was also used to measure distances. It consists of an ultrasonic transmitter and a receiver. It has four pins: VCC (power supply), Trig (input pin to send the ultrasonic pulse), Echo (output pin that

receives the reflected signal), and GND (ground). The basic operation of the HC-SR04 is as follows:

The transmitter emits a short-duration ultrasonic pulse.
The ultrasonic pulse propagates through the air as sound waves.
When these sound waves encounter an object, they are reflected back to the sensor.
The receiver captures the reflected signal.
The sensor measures the elapsed time between the pulse emission and the receipt of the reflected signal.
Based on the elapsed time, it is possible to calculate the distance between the sensor and the object using the speed of sound formula in air.

2.1.5 Bluetooth module

For wireless communication, the Bluetooth protocol was used in the system. With this in mind, a Bluetooth module was integrated into the mobile laboratory, allowing the sharing of data acquired by the IoT device with a connected smartphone. The chosen Bluetooth module was the HC-06, which is compatible with the interface of the Arduino Nano, the microcontroller used in the project.

Considering that the device will be mounted on a bicycle during cyclists' commutes, a power bank was chosen to provide power to the board. The power bank features a 18650 Lithium battery with a capacity of up to 3800 mAh and a continuous voltage of 3.7V. Connected to it is the TP4056 battery charging module, which allows for battery charging without removing it from the system and provides an output voltage of $4.2V \pm 1\%$.
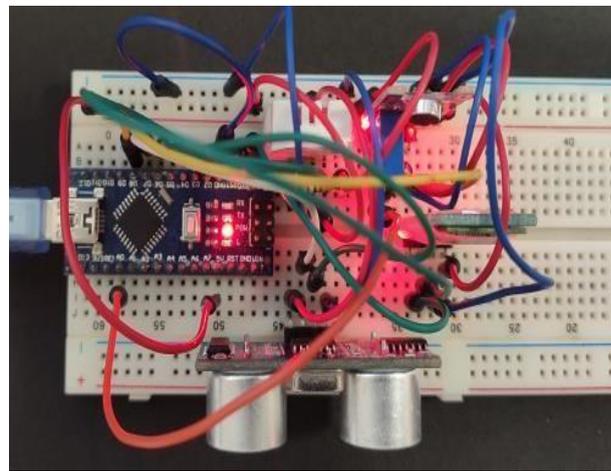
2.2 Hardware

The hardware of the project consists of a set of interconnected components powered by an external source, forming a mobile laboratory device. For the initial circuit prototyping, the components were selected and acquired, and then a preliminary model was created on a breadboard, taking into account the information from the datasheets to identify the power and communication pins of the components. This step allowed for verifying the connections and conducting initial tests, as shown in Figures 1 (A) and (B).

After this phase, the schematic and layout of the printed circuit board (PCB) were created using EAGLE software. The layout was transferred to a phenolic board using the photographic method, and then the components were soldered onto the board, completing the PCB fabrication process.
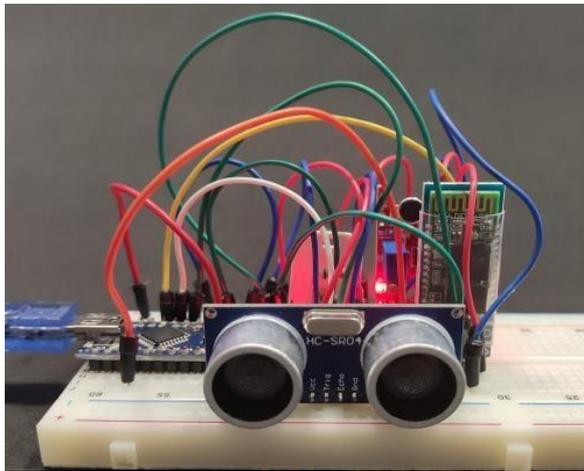
(A) (B)

Figure 1(A) and (B): Front and top views of the circuit mounted on the breadboard.

2.3 Software

The software plays a crucial role in bringing the hardware to life through a sequence of instructions that it executes to perform specific tasks. In the case of this project, the logical instructions were designed to interpret the data collected by the sensors and transmit it to the user's smartphone via Bluetooth. When designing the algorithm, the location of the IoT device on the bicycle and the minimum passing distance established by law were taken into consideration. Based on reviewed bibliographic references, it was decided to attach the mobile laboratory to the bicycle's handlebar, which serves as a support. Considering that most bicycles have a handlebar with an average length of 70 centimeters, and the IoT device was positioned exactly in the middle of the handlebar, an additional 35 centimeters were added to the minimum passing distance reference value of 1.50 meters (BRASIL, 1997).

Based on the provided data, the code was designed to recognize a dangerous overtaking when a car is at a distance

equal to or less than 1.80 meters from the IoT device. After determining the passing distance, the process of developing the lines of code began. Code sequences were created for testing purposes, developed in the Arduino IDE interface, to facilitate code uploading to the board and field tests using the C programming language. Final programming was also done in the VSCode platform.

The New Ping.h library is used for the HC-SR04 sensor and provides specific functions to measure the distance to the object and define the maximum distance supported by the sensor. The DHT.h library is used to directly read the temperature and humidity provided by the sensor. The SoftwareSerial.h library allows serial communication through the digital pins of the Arduino board. The Arduino.h library allows the use of Arduino framework functions and is accessed through the PlatformIO extension.

After processing the sensor data, it was necessary to organize the parameters to be sent via Bluetooth. For this purpose, a code sequence was used where each code makes use of functions from the DHT.h library to obtain the temperature and humidity values. Then, these values, along with the data from the other two sensors, are organized into a String (character sequence) to be sent through the bluetooth.print(btOut) function. This process occurs every ten seconds, as defined by the author.

2.4 User interface

The user interface developed for interaction has big importance as it is the key to stimulate the use of the application and consequently the creation of a growing database. For this purpose, a mobile application (Smart Mobility PRO) as previously mentioned, was created. The Android Studio platform was used for developing the application, and the Java programming language was used to create the programming algorithm. The software provides tools for direct interaction with Google, such as Firebase and Google Maps, proving to be efficient for the project. The layout of the application was designed based on concepts such as urban mobility, electrical engineering, and environmental protection. Figure 2 presents the project diagram.
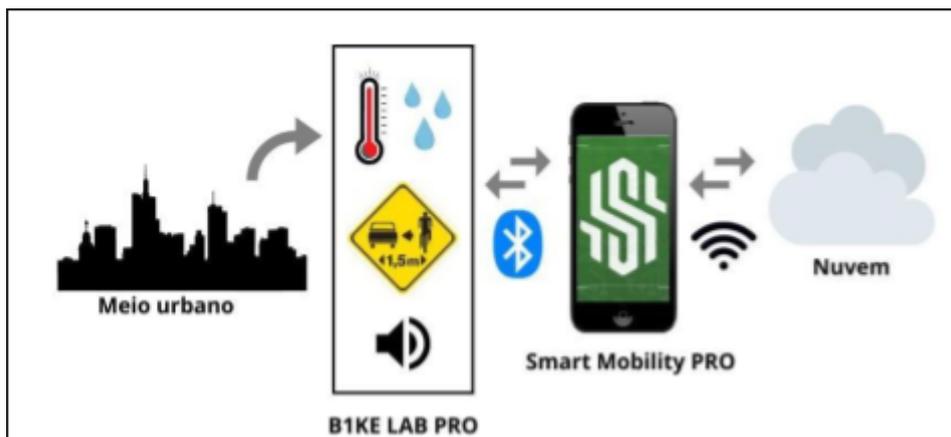

Figure 2: Project diagram.

3. RESULTS AND DISCUSSIONS

For the development of the device, the following components were used: Microcontroller: Arduino Nano, Bluetooth module: HC-06, Sound sensor: KY-038, Temperature and humidity sensor: DHT22, Ultrasonic sensor: HC-SR04, and external power source: 3800mAh Power bank.

3.1 Meteorological analysis of the system

The conditions applied to the analyzed sensors demonstrate low measurement errors, meaning that the values measured by the KY-038 differ very little from the DL-4200 values. However, it was only possible to make a direct comparison of the results since the used sound level meter has a resolution of 0.1 dB, and even within the anechoic chamber, it was not possible to obtain a fixed standard measurement value to be used as a reference for the measurements obtained by the sensor under study.

DECIBELÍMETRO DL-4200	MEDIDAS DO KY-038	ERRO DE MEDIÇÃO
30,2 dB	29,9 dB	0,3 dB
29,4 dB	29,5 dB	0,1 dB
29,7 dB	29,5 dB	0,2 dB
29,4 dB	29,5 dB	0,1 dB
29,6 dB	29,5 dB	0,1 dB

(A) KY-038 1

DECIBELÍMETRO DL-4200	MEDIDAS DO KY-038	ERRO DE MEDIÇÃO
28 dB	28,8 dB	0,8 dB
28,3 dB	28,3 dB	0 dB
27,6 dB	28,3 dB	0,7 dB
27,6 dB	27,9 dB	0,3 dB
27,6 dB	27,9 dB	0,3 dB

(B) KY-038 2

DECIBELÍMETRO DL-4200	MEDIDAS DO KY-038	ERRO DE MEDIÇÃO
26,8 dB	27,4 dB	0,6 dB
26,2 dB	27,4 dB	1,2 dB
26,4 dB	26,9 dB	0,5 dB
26,3 dB	27,4 dB	1,1 dB
26,6 dB	27,4 dB	0,8 dB

(C) KY-038 3

Figure 3: Sensor measurement errors.

For the metrological analysis of the DHT22 sensor, two steps were performed: temperature tests followed by humidity tests. The results of the tests presented in Figure 2 (A) and (B) display the data collected by different sensors.

MÉDIA ARITMÉTICA	DESVIO PADRÃO	CVP	TERMOPAR TESTO 310
28,8 °C	0,05 °C	0,19%	28,5 °C
19,2 °C	0,04 °C	0,23%	19,3 °C
27 °C	0,55 °C	2,03%	26,5 °C

(A) DHT22.1

MÉDIA ARITMÉTICA	DESVIO PADRÃO	CPV	TERMOPAR TESTO 310
28,8 °C	0 °C	0%	28,7 °C
21,9 °C	0 °C	0%	21,1 °C
27,1 °C	0,04 °C	0,17%	26,5 °C

(B) DHT22.2

MÉDIA ARITMÉTICA	DESVIO PADRÃO	CPV	TERMOPAR TESTO 310
29,4 °C	0,5 °C	0,19%	28,5 °C
20,5 °C	0 °C	0%	20,4 °C
27,3 °C	0,5 °C	0,2%	26,5 °C

(C) DHT22.3

Figure 4: Statistical calculations for five DHT22 temperature measurements.

With the study of the statistical method, it was possible to conclude the efficiency of the DHT22 sensor for temperature measurements, as indicated by the small difference between the arithmetic mean and the reference value, as well as the nearly negligible standard deviation and coefficient of variation (CVP). Following the temperature tests, humidity tests were conducted. These humidity tests were also performed, following a defined testing method where measurements were taken on three different days, with a reference measurement obtained from the standard system on each day. To illustrate the calculations and present the results obtained, Figure 5 was provided.

Please note that without the actual data and specific calculations presented in Figure 5, I am unable to provide a detailed analysis of the results. If you have any specific questions or need further assistance regarding the analysis and results, please provide more details or specify the information you would like to discuss.

PARÂMETROS	TERMO-HIGRÔMETRO 53% UR	TERMO-HIGRÔMETRO 50% UR	TERMO-HIGRÔMETRO 55% UR
	DIA 1	DIA 2	DIA 3
MÉDIA ARITMÉTICA	49,7% UR	46,7% UR	52,9% UR
DESVIO PADRÃO	0,13% UR	0,18% UR	0,49% UR
CVP	0,27%	0,39%	0,94%

(A) DHT22.1

PARÂMETROS	TERMO-HIGRÔMETRO 51% UR	TERMO-HIGRÔMETRO 49% UR	TERMO-HIGRÔMETRO 55% UR
	DIA 1	DIA 2	DIA 3
MÉDIA ARITMÉTICA	49,1% UR	46,5% UR	60,6% UR
DESVIO PADRÃO	0,19% UR	0,17% UR	0,21% UR
CVP	0,4%	0,38%	0,35%

(B) DHT22.2

PARÂMETROS	TERMO-HIGRÔMETRO 52% UR	TERMO-HIGRÔMETRO 49% UR	TERMO-HIGRÔMETRO 55% UR
	DIA 1	DIA 2	DIA 3
MÉDIA ARITMÉTICA	49,6% UR	44,1% UR	58,9% UR
DESVIO PADRÃO	0,11% UR	0,61% UR	0,04% UR
CVP	0,23%	1,38%	0,08%

(C) DHT22.3

Figure 5: Statistical calculations for ten measurements of sensors A, B and C.

With the reference to other devices that measure relative humidity, it was possible to interpret the results obtained and conclude that the DHT22 sensor is sufficient for measuring humidity in accordance with its application. Based on this final analysis and the conclusion regarding temperature measurements, the chosen sensor was sufficient for the task.

This confirms that the DHT22 sensor is suitable for measuring both temperature and humidity, as it has demonstrated accurate and reliable results compared to other reference devices.

3.2 Device design

For the design of this device, the EAGLE software was used to create the printed circuit board (PCB). The first step involved creating the schematic of the device, where all the components used in the project were added. Next, the placement of the components on the PCB was designed within the same software. Once the hardware was completed, the programming stage began using VSCode. The final stage of the system design included powering the board and assembling it with a protective case. The hardware and power bank were arranged to occupy the smallest possible space. To optimize battery usage, an On/Off toggle switch was installed. The final product weighed approximately 160 grams and had dimensions of 10.8 centimeters in length, 8.3 centimeters in width, and 4.9 centimeters in height, as shown in Figure 6 below.

Figure 6: IoT device top and front view.

For this project, three devices were developed, with a final cost of approximately R$ 300.00 per device. This cost is relatively low considering the functions it serves, making it affordable for large-scale production. As a result, distributing 100 devices to cyclist organizations, delivery services, and enthusiasts would easily allow for monitoring of large areas of cities. It is important to highlight that the IoT device is user-friendly and easy to install, without altering the cyclist's habits.

With the developed system, tests were conducted regarding battery life. The IoT device was connected to a smartphone, and data was sent continuously for twelve hours, resulting in a decrease of 0.16V in the battery voltage. Based on the results obtained, it was concluded that the chosen battery is sufficient for the project, lasting up to twelve days of constant use.

3.3 User interface

The interface created for the application that connects to the IoT device plays an important role in data collection. Through direct interactions with the user, it was possible to identify the mode of transportation being used, establish a Bluetooth connection with the IoT device, receive data from the device, and finally store the parameters in the cloud. The application is fully intuitive, allowing the user to define the type of transportation, access real-time location data, set routes, save these routes, and consequently collect the data. Screenshots of the application are presented below (Figure 7).
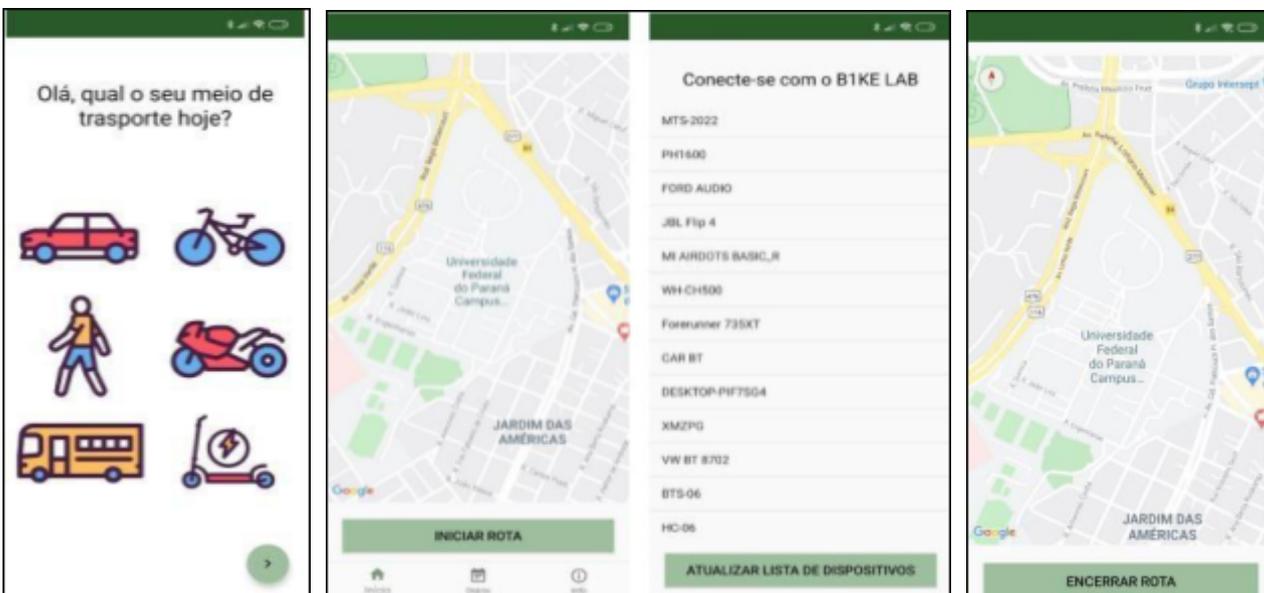

Figure 7: Application user interface.

After the development of the IoT device, it was integrated into the application to start collecting data according to the specified conditions. Initially, the device was attached to a bicycle. In addition to this, travel was conducted using other modes of transportation such as car, walking, and motorcycle. These trips facilitated the collection of data, which was stored in the Firebase database, a platform that stores data in JSON format. This platform transmits and stores information in a self-descriptive configuration, making the stored data easily understandable to the reader. To differentiate the trips, identification keys were created, containing the chosen mode of transportation by the user, the date, and the start time of the route. Each of the unique keys generated identifies and stores the data sent by the IoT device and the GPS location from the smartphone, approximately, every two seconds. For travels that do not use the IoT device, only the location data is stored.

In the application, the user can track the creation of their route in real-time. The trips are also presented in the "Diary" tab, where each saved trip is represented by a card displaying the following information: date and time of route start, distance traveled, and for users who used the developed application, the total number of dangerous overtakings experienced, as well as the minimum, average, and maximum values of humidity, temperature, and sound intensity throughout the journey.

Finally, the application also provides a section that includes i) the route taken, ii) humidity by section, iii) temperature by section, iv) number of overtakings by section, and v) sound intensity by section, all presented with a color-coded scale that varies according to the user's route.

4. CONCLUSION

The project proposed the development of an IoT device for collecting environmental and cycling parameters. Initially, studies were conducted on related topics and the components that make up the device. Subsequently, the presented methodology was applied with the intention of conceiving the system.

The main conclusions of this work are as follows:

- For the collection of environmental parameters, the DHT22 sensors (temperature and humidity) and the KY- 038 sensor (sound) were used. In addition to these, the HC-SR04 ultrasonic sensor was selected to quantify dangerous overtakings experienced by cyclists. Integrating the sensors, the Arduino Nano microcontroller processed the data and transmitted it through the HC-06 Bluetooth module. The 3800mAh 18650 lithium battery supported the system.

- The metrological test of the HC-SR04 and DHT22 sensors, through the calculation of the standard deviation and the coefficient of variation, yielded considerably low values, demonstrating the efficiency of these sensors for the application in the project. However, in relation to the metrological test of the KY-038 sensor, the possible tests performed were insufficient to validate the accuracy of the measurements. Nonetheless, there were technical and financial resources available for obtaining the final system.

- Through the presented methodology, it was possible to conceive the IoT device with Bluetooth communication. It connected to the smartphone through the developed application, the Smart Mobility PRO, which transmitted the collected data and GPS location, which were saved in the Firebase Realtime Database, a cloud-based database.

- After the development of the IoT device and the storage system, travel was conducted to collect parameters and feed the database. At the end of the project, the created database is not yet sufficient for sharing with public and private institutions. However, it serves as a project model to be presented to investors.

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