A Low-Cost Wearable Autonomous System for the Protection of Bicycle Users

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***Abstract*—A bicycle is a form of transport that not only positively impacts the health of users, and the general population by reducing pollution levels but also constitutes an accessible and affordable means of transport for developing societies. However, when coexisting with other forms of transport, the accident rate is elevated, and the risk is high. Among the factors contributing to accidents involving bicycles are collisions with motor vehicles. These accidents can occur when a motor vehicle maneuvers and does not see the bicycle or when a motorist drives distracted. These types of accidents can be avoided if cyclists and motorists are aware of the environment and respect traffic laws and safety regulations. This research aims to develop a low-cost autonomous electronic system that provides extra protection to bicycle users, particularly by making them visible to other road users on cloudy days or at night. The system uses a 32-bit processor with brightness and acceleration sensors that trigger visual alerts to both the bicycle user and possible nearby vehicles. It also monitors and logs the signals on a server for route evaluation. The laboratory successfully evaluated the prototype, demonstrating its autonomy and performance. The test results obtained demonstrate the system's capacity to provide extra protection, in addition to its robustness and accuracy.**

***Keywords*—Autonomous system; bicycle users; embedded system; protection; wearable**

I. Introduction

The bicycle is a mode of transportation that has gained increasing importance in developing countries such as Colombia due to its multiple benefits [1]. First, it is an affordable and accessible form of transportation for many people who cannot afford to buy or maintain a motorized vehicle [2]. In addition, the bicycle is an environmentally friendly means of transportation, as it does not emit polluting gases or produce noise, making it an attractive option in urban environments where air pollution and noise can be severe problems [3].

Another advantage of the bicycle as a means of transportation is its positive impact on people's health [4]. Cycling as a means of transportation is a physical activity that can help improve cardiovascular fitness and burn calories, which can help prevent diseases related to sedentary lifestyles [5]. Furthermore, in developing countries where access to health services can sometimes be limited, cycling can effectively improve the population's health [6].

Cycling can also be an efficient form of transportation in environments with little or no road infrastructure [7]. In many developing countries, road infrastructure can be poor or non-existent, making cycling a practical and effective form of transportation [8]. In addition, cycling as a mode of transport can help reduce traffic congestion in cities, as it takes up less space on roads and streets.

Despite its many benefits, cycling also needs some help as a means of transportation [9]. One of the main problems is the need for adequate cycling infrastructure in many cities and rural areas [10]. This can include a need for dedicated bicycle lanes or safe and adequate parking spaces. This lack of infrastructure can make it difficult and dangerous to use bicycles as a means of transportation in some areas.

Another problem is the need for more acceptance and respect by motor vehicle drivers for bicyclists [11]. So often, drivers are not habituated to sharing the road with cyclists and may be inconsiderate or hostile towards them [12], [13]. This can make it difficult and dangerous for cyclists to share the road with motor vehicles.

Bicycle user accidents in developing countries are a serious and worrying problem [14]. Bicycle accidents can have severe consequences for those involved, including serious injury or death. In addition, bicycle accidents can have a significant economic and social impact, as they can require costly medical care and disrupt people's ability to work and support their families.

Several factors can contribute to bicycle accidents [15]. One of the main factors is the need for adequate infrastructure for bicyclists, such as dedicated bicycle lanes or safe and adequate places to park bicycles. This lack of infrastructure can make it difficult and dangerous to use bicycles as a means of transportation in some areas. However, the most critical factor is the need for more awareness and respect by motor vehicle drivers for cyclists [16]. Often, drivers are not accustomed to sharing the road with cyclists and may be inconsiderate or hostile towards them. In addition, lighting and visibility conditions on the road increase the risk of bicycle accidents.

Lack of adequate lighting on roads and streets is a significant factor in nighttime bicycle accidents [17], [18]. When there is little or no lighting, it can be difficult for bicyclists and other road users to see obstacles or potential hazards, increasing the risk of accidents [19]. In addition, poor lighting can make it difficult for motor vehicle drivers to see bicyclists, which can also increase the risk of crashes [20].

This research proposes a low-cost electronic system capable of increasing the visibility of bicycle users [21]. This system incorporates a 32-bit microcontroller with two cores capable of high-speed response and Wi-Fi and Bluetooth communication [22], [23]. This processor works hand in hand with an illumination level sensor (illuminance) to identify risk states and generate visual and acoustic alerts [24], [25].

The problem addressed in this research is the high accident rate of bicycles when coexisting with other forms of transportation, particularly motor vehicles. Bicycle accidents can occur when a motorist does not see the bicycle or when the motorist is distracted. These accidents can have severe consequences for cyclists, including injury or death.

One contributing factor to these accidents is the difficulty in seeing bicycles, especially on cloudy days or at night. Cyclists may not be visible to other road users, leading to collisions. In developing societies, where bicycles are often an affordable and accessible form of transportation, this problem is especially relevant.

To address this problem, the research aims to develop a low-cost autonomous electronic system that provides extra protection to bicycle users by making them more visible to other road users. The system uses a 32-bit processor with brightness and acceleration sensors that trigger visual alerts to both the bicycle user and nearby vehicles. It also monitors and logs the signals on a server for route evaluation. The goal is to create a robust, accurate system, and capable of providing extra protection to bicycle users to reduce the risk of accidents.

The following section presents a review of the background considered in the design of the prototype, both at the functional and implementation levels. The methods section summarizes the design criteria, its implementation, and system usage considerations. The results section presents the performance tests and the behavior recorded in laboratory conditions, and finally the conclusions section presents the summarized results.

II. Background

In recent years, there has been a growing interest in the development of innovative Human Activity Recognition (HAR) systems that exploit the potential of wearable devices integrated with deep learning techniques. One such example is presented by [26], who propose an innovative HAR system with the aim of recognizing the most common daily activities of a person at home. The authors use a combination of wearable sensors and deep learning techniques to accurately classify activities such as walking, sitting, and standing. They evaluate the performance of their system using a dataset of daily activities collected from 20 participants and achieve an overall accuracy of 96.7%. This study highlights the potential of using wearable devices and deep learning techniques for accurate recognition of daily activities.

Another area of research in the field of robotics and intelligent systems is the design and construction of low-cost Internet of Things (IoT) sensor meshes for remote measurement of parameters. The author in [27] present a design and construction of a low-cost IoT sensor mesh that enables the remote measurement of parameters of large-scale orchards. The authors propose the use of a mesh network of low-cost, low-power sensors to collect data on temperature, humidity, and soil moisture. The sensor mesh is designed to be easy to deploy, maintain and provides real-time data to the farmers. The system is evaluated in a commercial orchard and the results demonstrate that it can accurately measure temperature, humidity, and soil moisture.

[28] explore the technical development of a multi-user multi-modal traffic simulation platform that expands on the capabilities of traditional traffic simulators. The authors propose a platform that combines traditional traffic simulation with virtual reality (VR) technology, allowing for multi-user and multi-modal simulations. The platform is evaluated through a case study of a complex urban intersection and the results demonstrate its ability to accurately simulate traffic flow and pedestrian behavior. This study highlights the potential of using VR technology to enhance the capabilities of traditional traffic simulation platforms and improve their accuracy in simulating complex traffic scenarios.

[29] introduce a novel low-cost solar-powered wearable assistive technology (AT) device, whose aim is to provide continuous, real-time object recognition to ease the finding of the objects for visually impaired (VI) people in daily life. The authors propose the use of a low-cost, solar-powered wearable device equipped with a camera and a deep learning-based object recognition system. The device is evaluated through user studies with VI individuals and the results demonstrate its ability to accurately recognize objects in real-time and improve the independence of VI individuals in their daily life.

[30] present a new “active mask” paradigm, in which the wearable device is equipped with smart sensors and actuators to both detect the presence of airborne pathogens in real time and take appropriate action to mitigate the threat. The authors propose the use of an active mask equipped with sensors for detecting airborne pathogens and actuators for releasing disinfectants. The device is evaluated through laboratory tests and the results demonstrate its ability to accurately detect pathogens and effectively release disinfectants.

[31] aim at helping the mobility-challenged individuals with a novel robotic companion, which is a walker-type mobile robot capable of accompanying the human user and keeping user at the center for protection and possible power assistance. The authors propose a robot that can assist mobility-challenged individuals with navigation, object recognition, and power assistance. The robot is evaluated through user studies with mobility-challenged individuals and the results demonstrate its ability to improve the independence and safety of the users.

[32] use VR 360° panoramic technology to develop a virtual wetland ecological system for applications in environmental education. The authors propose the use of VR technology to create an immersive virtual wetland ecosystem for educational purposes. The virtual wetland is evaluated through a user study with students and the results demonstrate its ability to improve the understanding and engagement of students in learning about wetland ecology. This study highlights the potential of using VR technology in environmental education to create immersive and interactive learning experiences.

[33] present a new “active mask” paradigm, similar to the one presented by [30], in which the wearable device is equipped with smart sensors and actuators to both detect the presence of airborne pathogens in real time and take appropriate action to mitigate the threat. The authors propose an active mask equipped with sensors for detecting COVID-19 and actuators for releasing disinfectants. The device is evaluated through laboratory tests and the results demonstrate its ability to accurately detect COVID-19 and effectively release disinfectants.

[34] introduce an artificial intelligence-powered multi-modal robotic sensing system (M-Bot) with an all-printed

mass-producible soft electronic skin-based human-machine interface. The authors propose a robot that can sense and interact with its environment through an electronic skin interface. The robot is equipped with AI algorithms for object recognition and tactile sensing. The robot is evaluated through laboratory tests and the results demonstrate its ability to accurately sense and interact with its environment through its electronic skin interface.

[35] develop an air quality monitoring platform that comprises a wearable device embedding low-cost metal oxide semiconductor (MOS) gas sensors, a PM sensor, and a smartphone for collecting the data using Bluetooth Low Energy (BLE) communication. The authors propose a wearable device for monitoring air quality, specifically for PM and gas pollutants. The device is evaluated through laboratory tests and the results demonstrate its ability to accurately measure PM and gas pollutants in the air.

III. Methods

The project's objective was to develop a low-cost wearable system (accessible to the average user) with high processing and communication capabilities. To meet these criteria, a vest was developed with embedded electronics equipped with sensors and display units, both for the user and individuals on the road. The control unit selected was the ESP32 SoC (System On a Chip) from Espressif Systems, which is supported by a 32-bit, dual-core Tensilica Xtensa LX6 microprocessor. This processor supports a clock frequency of up to 240 MHz, with a performance of up to 600 DMIPS (Dhrystone Million Instructions Per Second). In addition, the SoC has Wi-Fi/Bluetooth functionalities that cover the protection system's communication requirements.

The protective vest also incorporates other essential safety elements for urban cyclists, among them are the following:

- **Reflective elements:** The vest includes reflective stripes and other reflective elements to help make the wearer more visible to other road users, especially in low-light conditions.
- **High visibility colors:** The design of the vest uses brightly colored and evident materials, such as neon yellow and orange, to help improve visibility.
- **LED lights:** A signaling system with LED lights have been incorporated into the vest to increase visibility. The protection system control unit controls these lights.
- **Breathability:** Breathable materials have been used in the vest design, which is especially important if you are cycling in hot climates to avoid overheating.
- **Fit:** The vest incorporates adjustable straps to fit different body types. To improve safety, a good fit should be ensured, and comfort should be improved.
- **Durability:** The vest must be made of durable materials that can withstand regular use and wear.
- **Water resistance:** Special care was taken to ensure that the vest would function in wet conditions. In addition, a water-resistant vest can help keep the wearer dry and comfortable.

A series of sensors were incorporated into the control unit, including the illuminance sensor (luminous flux per unit area). The BH1750 sensor was used, a digital light sensor that measures in Lux (lumen/m^2). The sensor uses I^2C communication, has high precision, and ranges from 1 to 65535 lx. This sensor was calibrated in the laboratory with a reference lux meter in a dark room with lighting control (Fig. 1). Low values correspond to low illumination conditions, and high values to high illumination conditions. The measured error averaged 4.8%, with maximum values of 14.6%.

Other sensors and peripherals incorporated into the system include:

- A U-Blox NEO-6M GPS (Global Positioning System) U-Blox NEO-6M, a high-accuracy, low-cost GPS module for global tracking.
- A GY-521 MPU-6050 module incorporating a gyroscope and accelerometer, both with MEMS technology, has six axes of freedom (three axes of the accelerometer and three axes of the gyroscope).
- Two 32×8 pixel LEDs grid with Bluetooth to alert people close to the cyclist.
- One 84×48 pixel monochrome graphic display with PCD8544 controller for communication with the user.
- A small Lithium-ion (Li-ion) battery pack.

A road safety vest for cyclists is a portable system designed to increase the visibility and safety of cyclists when riding on the road. Functionally, the essential part is the control unit, based in our case on the ESP32 SoC, which is responsible for processing the inputs coming from the sensors and controlling the output of the vest. The following describes in detail how the control unit of the road safety vest works with illuminance sensors, gyroscope, accelerometer, GPS, and LED displays to show the status to vehicle drivers and a display to inform the user.

First, let's consider the role of the illuminance sensors. These sensors detect the ambient light level in the environment where the vest is being worn. This information is vital because the vest's LED displays, which communicate the wearer's status to vehicle drivers, need to be bright enough to be seen in low-light conditions but not too bright to be distracting in bright-light conditions. The SoC control unit will use the illuminance sensors' data to adjust the LED displays' brightness accordingly. The information displayed is congruent with the state of the cyclist, which is supported by the accelerometer. Therefore, this information is accentuated in the LED array, as well as if he/she is stopped or brakes suddenly.

Next, let's consider the role of the gyroscope and accelerometer. These sensors are used to detect the movement and orientation of the vest. The gyroscope measures angular velocity, which allows the microcontroller control unit to determine the vest's orientation in space. The accelerometer measures acceleration, which allows the microcontroller control unit to determine the vest's movement. This information is helpful for several reasons. For example, suppose the vest is

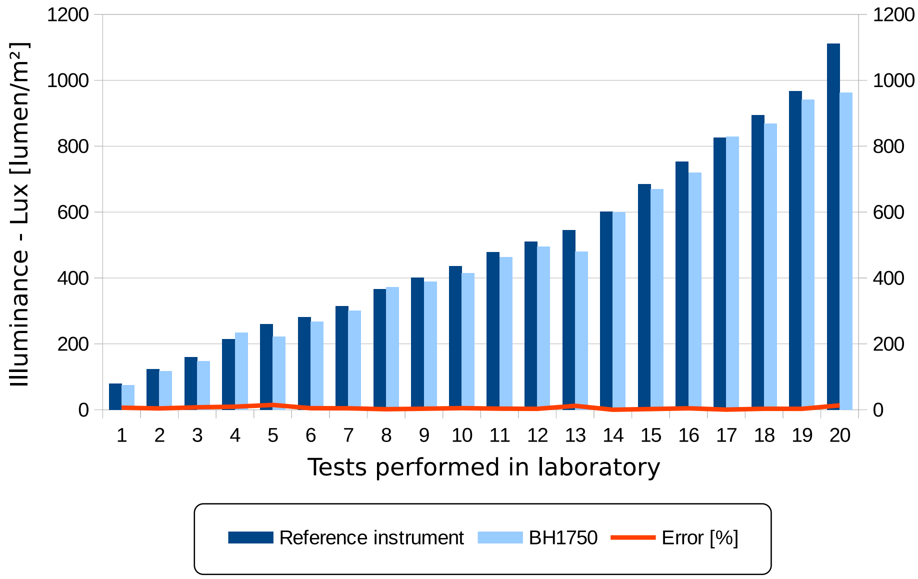

Fig. 1. Illuminance sensor vs. reference sensor characteristics

worn while cycling. In that case, the accelerometer can detect when the wearer is braking or accelerating, which can activate the LED displays to alert vehicle drivers of the wearer's intentions. Likewise, the gyroscope can detect when the wearer is turning, which can also activate the LED displays to alert vehicle drivers of the wearer's intentions.

The GPS (Global Positioning System) sensor determines the vest's location. This information is used by the SoC control unit to display the wearer's location on the display screen and to report the tracking information to a web server, which can be helpful for navigation purposes. Additionally, the GPS data can activate the LED displays when the vest is approaching a location where it is vital for the wearer to be more visible, such as a busy intersection.

The LED displays on the vest are used to communicate the wearer's status to vehicle drivers. For example, the LED displays can be activated to show a solid red light when the wearer is braking, a solid yellow light when the wearer is turning, and a solid green light when the wearer is accelerating. The LED displays can also display a flashing red light when the vest is approaching a location where it is crucial for the wearer to be more visible, such as a busy intersection.

Finally, the vest should also have a display screen to inform the user of various information, such as the vest's battery level, the current time, and the wearer's location on a map. The SoC control unit can use the data from the various sensors to update this information on the display screen in real time.

The SoC control unit of the road safety vest incorporates illuminance sensors, a gyroscope, accelerometer, GPS, LED displays to show the status to vehicle drivers, and a display to inform the user should function by using the data from the various sensors to control the output of the vest. The illuminance sensors are used to adjust the brightness of the LED displays, the gyroscope and accelerometer are used to detect the vest's movement and orientation, the GPS sensor is used to determine the vest's location, and the LED displays are used to communicate the condition of the cyclist to other road users, primary drivers of motorized vehicles (Fig. 2).

IV. Results and Discussion

The performance evaluation of the system was aimed at ensuring that the vest effectively increases cyclists' visibility and safety when riding on the road. In this regard, firstly, the role of illuminance sensors was considered. The performance of these sensors can be evaluated by measuring the accuracy of the ambient light level readings they provide. This was done by comparing the sensor readings with the actual ambient light level in the environment using a light meter. The sensors must provide accurate readings because the vest's LED displays, which are used to communicate the wearer's status to vehicle drivers, must be bright enough to be seen in low light conditions but not too bright to be distracting in bright light conditions (Fig. 3).

Another critical part of the testing considered the role of the gyroscope and accelerometer. The performance of these sensors was evaluated by measuring the accuracy of the angular velocity and acceleration readings they provide. This was done by comparing the sensor readings with the actual angular velocity and acceleration of the vest using a separate device (a gyroscope and a high-precision accelerometer). The sensors must provide accurate readings because they are used to detect the vest's motion and orientation, which activate the LED displays that alert vehicle drivers of the wearer's intentions.

The performance of the GPS (Global Positioning System) sensor was evaluated by measuring the accuracy of the location readings it provides. This was done by comparing the sensor readings with the actual location of the vest using an independent GPS device and a map. Accurate location readings are essential for the sensor because the vest's display uses this information to show the user's location. This information is also used to track the user on the Internet. In addition, the

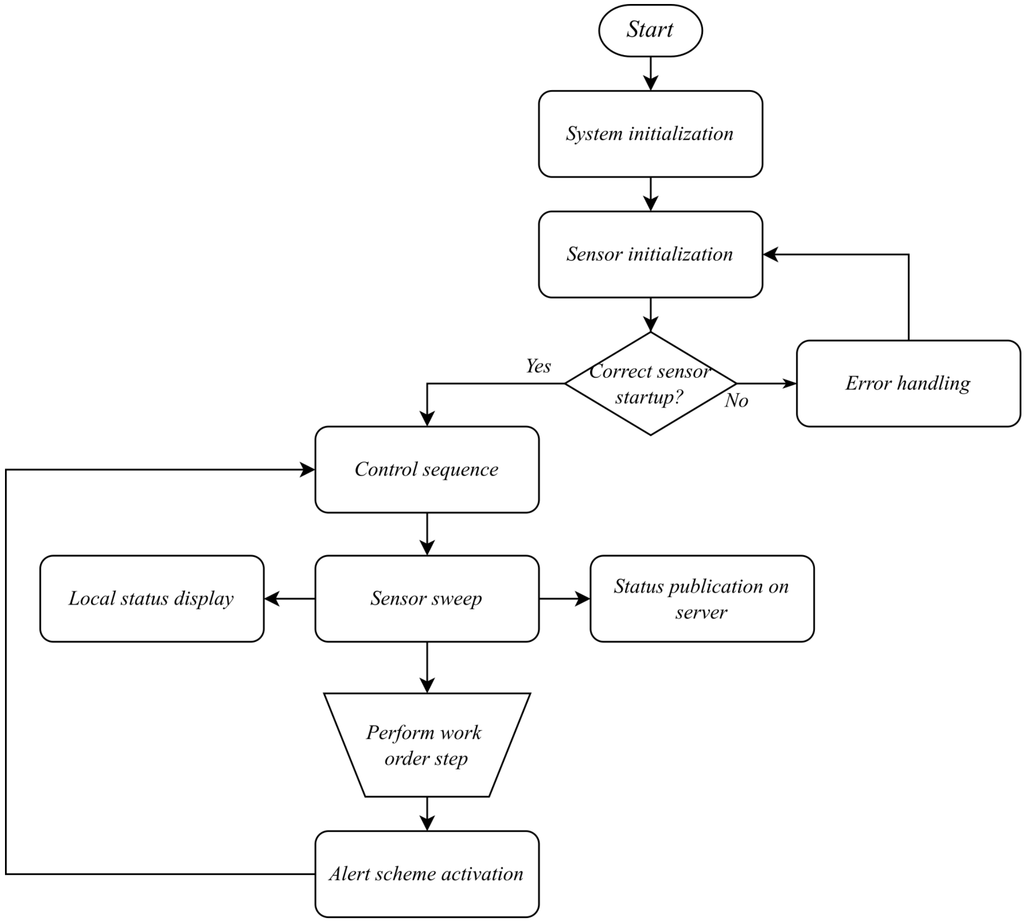

Fig. 2. Proposed operating strategy

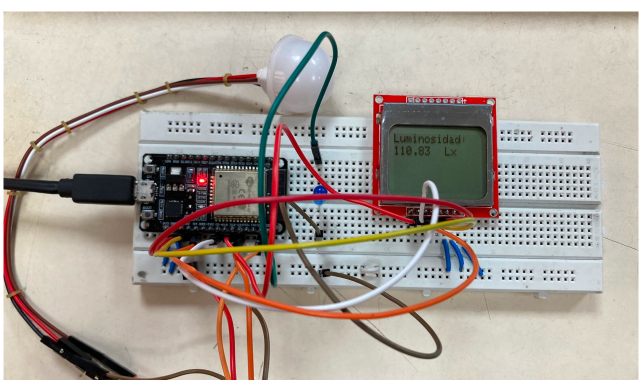

Fig. 3. Illuminance sensor tests

GPS data is used to activate the LED displays when the vest approaches a location where it is vital for the wearer to be more visible, such as a busy intersection.

The performance of the LED displays was evaluated by measuring their visibility from different distances and angles. This was done by observing the displays from different positions while wearing the vest and comparing the visibility to a standard. The displays must be evident from a distance and at different angles as they communicate the wearer's status to vehicle drivers.

Finally, the performance of the display screen that informs the user of various data, such as the vest's battery level, the current time and the user's location coordinates, was evaluated by measuring the accuracy and readability of the information it displays. This was done by comparing the information displayed on the screen with that of another device and by viewing the screen from different positions while wearing the vest. The display screen must provide accurate and legible information because it is used to inform the wearer of various vital details. In addition, the logging of information of all variables detected by the vest to the web server was verified, which should include the date and time information, and match the information displayed to the user in real-time (Fig. 4).

In summary, the cycling safety vest's performance meets the design profile's performance expectations. It has an excellent response to changes in illuminance and provides high visibility by combining LED lights with bright, high-visibility colors. The response characteristics to sudden changes in acceleration and geographic location increase user protection in situations beyond their control. The system will be further tested for mechanical robustness, ergonomics and comfort to meet additional design parameters.

Fig. 4. Tracking of system variables

V. Conclusion

In conclusion, the proposed safety vest for cyclists is a portable and innovative device that aims to improve the visibility and safety of cyclists on the road. The vest incorporates illuminance sensors, a gyroscope, an accelerometer, GPS, and LED displays to show the status to vehicle drivers and a display to inform the user. The SoC that controls the vest is responsible for processing the information from the different sensors and controlling the output of the vest. The illuminance sensors measure the ambient light level in the environment in which the vest is worn, which is vital for adjusting the brightness of the LED displays accordingly. The gyroscope and accelerometer, meanwhile, measure the movement and orientation of the vest and are used to activate the LED displays and alert vehicle drivers of the wearer's intentions. The GPS sensor determines the location of the vest. It is used to display the wearer's location on the screen and to activate the LED displays when the vest approaches a location where the wearer needs to be more visible, such as a busy intersection. All detected information is transmitted in real-time to a web server for logging and tracking. LED displays are used to communicate the user's status to vehicle drivers, showing solid red light when the user brakes, solid yellow light when turning, and a solid green light when accelerating. They can also be used to display a flashing red light when the vest approaches a location where the wearer needs to be more visible. Finally, the vest also has a display that informs the user of the vest's battery level, the current time and the user's location on a map.

The results of the laboratory tests show that the vest is a well-designed and effective device that can significantly improve the visibility and safety of cyclists. The ability to adjust the brightness of the LED displays based on the ambient light level detected by the illuminance sensors ensures that the displays are always visible to vehicle drivers, regardless of lighting conditions. In addition, the gyroscope and accelerometer allow the vest to detect the wearer's movement and orientation, which can activate the LED displays and alert drivers of the wearer's intentions. Finally, the GPS sensor allows the vest to determine its location, which can be displayed on a map on the display screen for navigation purposes and used to activate the LED displays when the vest approaches a location where the wearer must be more visible.

Future work on this vest could include the integration of additional sensors, such as a heart rate monitor, to provide the user with even more information about their physical condition while cycling. Another potential improvement could be the integration of a communication system, such as a two-way radio, to allow the user to communicate with other cyclists or vehicle drivers in their vicinity. Additionally, the vest could be integrated with a smart phone app that allows the user to remotely control the vest's functions and view real-time data from the sensors. Finally, further testing and evaluation of the vest in real-world conditions, including in different weather conditions, would help to further optimize its performance and effectiveness.

Acknowledgment

This work was supported by the Universidad Distrital Francisco José de Caldas, specifically by the Technological Faculty. The views expressed in this paper are not necessarily endorsed by Universidad Distrital. The authors thank all the students and researchers of the research group ARMOS for their support in the development of this work.

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