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Intelligent Bicycle Safety and Tracking System: A GPS and GSM-Based Approach

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Abstract: *Bicycles are affordable and healthy, cause zero harm to the environment, require little space on roads and parks, and are not noisy transportation means. However, cyclists face challenges on roads, which may lead to injuries and deaths. For instance, cyclists visibility, speed management, ability to communicate with other road users, backward accidents, and ability to be located in urgent cases. This paper presents performance, tracking, and safety systems from hardware and software point of view. As a result, cyclists monitor their speed to manage; their locations are tracked, and their cycling paths are traced. Also, a rear red light and turn signal LEDs are activated without any physical action from the rider to communicate with other drivers. Moreover, a microwave radar sensor with a range of seven meters is employed to protect the cyclist from backward-approaching vehicles. Finally, three Arduino UNO boards with GPS, GSM modules, MPU-6050, and RCWL-0516 sensors are mounted on a conventional bicycle to provide safer trips.*

Keywords: *Bicycle communication with other road users, bicycle speed monitoring, bicycle visibility, bicycle rear-end protection, location tracking.*

1. INTRODUCTION

In 2020 and 2019, there were 229 and 203 cyclist deaths in the Netherlands [1]. In 2016, the bicyclist deaths were 840, whereas in 2014 were 729 with 50,000 injuries in the USA [2]. It is recognized that the majority of bicyclist deaths occurred because of hitting from behind. 23% of these accidents occurred on straight roads, and 16% percent occurred on carved roads [3]. So, how does the cyclist improve their visibility to drivers who are approaching from behind [2].

Toward providing sustainable and safe mobility in modern cities. Cycling is considered one of the most sustainable and less harmful emissions transportation means, healthy, cost-effective, and relaxing [1] [4]. However, the danger on the cyclists in roads is higher than on motorists [5]. So, there is a need to study more about cyclists' road safety. To summarize the challenges that face cyclists: less ability to be seen, inadequate communicating with other road users, inability to know their speed, rear-hit accidents, and bicycle location tracking.

Adding a microcontroller-based systems to the conventional bikes, convert them to be smart vehicles. This assists riders to be safer on roads. So, this paper proposes three systems: A performance system monitors bicycle speed; a location tracking and cycling paths tracing system; and a safety system includes rear red light and turn signal lights

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controlling, and rear vehicles motion detection system. Lastly, this article tries to answer how microcontroller-based systems can boost cycling safety with less rider interaction.

Related works

Making cyclists be visible on roads is crucial for a safer ride. Therefore, as much as adding more visibility-related accessories, a safer ride can be achieved. For example, adding a red taillight, light reflectors, extra lights on the handlebar, helmet, and cyclist's leg [6]. Furthermore, brake lights are important for enhancing visibility, driver safety, and avoiding rear-end collisions. To be more specific, flashing brake lights reduce the brake response time by 3-7%, which means flashing brake lights are better than steady brake lights. The flashing frequency of less than 7 Hz does not affect the brake response time of the following drivers [7].

Accidents with bicycles can happen even during daytime, so the flashing taillights play a vital role in bicycle daytime visibility. Taillight configurations can provide a promised solution to make bicyclists easy to be recognized and detected by other road users to avoid incidents. The bicycle was recognized with greater distance when there was a flashlight or a steady light than no taillight present. The flashing light is better than the steady light in detecting and recognizing bicycles; it is also better in estimating and recognizing the distance between the bicycle and the following vehicles [2]. Moreover, in [8], four rear light configurations of static red light, steady flash light, reactive flashing, and no light were tested during day and dusk time to study bicycles visibility. Drivers were able to recognize the bicycles of the three configurations. However, their ability to estimate the distance between them and the bicycles was better with steady flash red lights and reactive flash red lights.

Location tracking is achieved by combining the functionality of GPS and GSM modules. The GPS (Global Positioning System) module provides three types of data: geographical coordinates, speed, and time. While the GSM (Global System Mobile communication) module sends SMS messages to other devices wirelessly using local mobile communication networks (cellular networks). A tracker sent a "find message" from a phone to a bicycle. An Arduino board received the message via the GSM and sent back the location in "NMEA" format. Then, the tracker utilizes the Google Maps application to identify the pinpoint location [9]. In addition, in [10], when the tracker sends the "ON" string, the bicycle sends its location back to the tracker, while if it was the "OFF" string, the bicycle sends its location to local authorities to take action because the bicycle is considered stolen. However, other projects made the tracking system on the bicycle share its location automatically whenever the accident occurs [11] or share the location whenever the bicycle rider presses on a specific push/button switch [12]. On the other hand, [13] provided a system to warn cyclists while they passed through certain areas that were identified as dangerous neighborhoods beforehand using an online platform called “OpenStreetMap (OSM).” After that, the latitude and the longitude values of those areas are exported as a .CSV file and imported into the embedded system. Therefore, wherever the cyclists cross those areas, warning light and buzzer are activated.

One of reasons to have accidents with bicycles is being drunk and the possibility of getting serious injuries when the rider does not wear a helmet [14] [15]. Consequently, [15] [16] presented as a system included two parts. One mounted on the cyclist’s helmet and the other on the bicycle itself. The helmet was equipped with two kinds of sensors: an MQ3 gas sensor to detect if the rider is drunk and a force-sensing resistor (FSR) to detect if the helmet is being worn. If not, a warning light appeared on an LCD screen in front of the rider. A 433MHz RF module was used to secure wireless communication between the helmet and the system. The second part of the system includes the DFR0027 vibration sensor for fall detection. As a result, if the rider was drunk and an accident happened, or falling was detected, the system sent an SMS that included the location to predefined phone numbers. While, in [17], they replaced the vibration sensor with the SW-420 and they identify a speed limit. When it was crossed, a warning message appeared on the LCD screen. Whereas, [18] proposed a system, in emergency situations, keeps sending location SMS until it receives an acknowledgment from a health giver or a cyclist’s relative.

Rear collisions are registered with a very high rate of occurrence on roads. To solve this issue, an ultrasonic sensor is used to check the distance between the bike and other vehicles behind it. If the distance is not secure, a light indicator in front of the cyclists to warn them to turn [19]. Additionally, a hand gesture recognition technique employing two IR sensor (LED and photodiode) to control turning signals for enhancing the communication with other road users. However, in [20], a laser sensor, mounted on a stage behind the rider seat, moves rotationally to detect vehicles approaching from behind, and it gives a sonic alarm to make the rider pay attention which avoid rear collisions.

Bicycle speed Monitoring can be achieved by three methods: manual way (stopwatch, measuring tape, and radar gun), semi-automatic way (a pneumatic tube counter, magnetic reed switch sensor, GPS, and image analysis frame by frame manually from video camera), and automatic way (automated image analysis from video camera using computer vision technique) [4]. When magnetic reed switches or Hall effect sensors are used to measure the bicycle speed or the cycling distance, mathematical equations are applied to calculate those parameters. The limitation of the Hall effect sensor is that it can detect up to 542 revolutions per minute [21]. The GPS-based speed accuracy increased on the straight paths, while errors increased on circular paths, especially with a small radius of curvature. It is more accurate in steady acceleration status than in fast and sudden speed changes [22].

This paper is organized as follows: section two is methodology, which explains the design and implementation of three sub-systems from hardware and software perspectives. Then, section three results and discussion, which shows the application outcome of all proposed systems. Next, in section four is the conclusion. Finally, the future work section shows project's limitations and how it can be improved.

2. METHODOLOGY

Overview

This project includes three subsystems that aim to improve the bicycle riding safety. These systems depend on the Arduino UNO boards and some sort of sensors and modules to monitor bicycle's speed, bicycle's location tracking, rear red light and turn signal LEDs automatic activation, and rear radar vehicle motion detection. All these systems are mounted on the bicycle itself.

System design and architecture

A bicycle transmits its location via a GSM module whenever it receives a find text message from a tracker phone. Also, cyclists monitor their speed on an LCD screen on the handlebar. Furthermore, a flashing red taillight is employed to boost bicycle's visibility. In addition to turn signals (right and left), to communicate with other road users. Finally, a motion detection sensor to warn cyclists about any object that gets closer from behind. See figure 1.

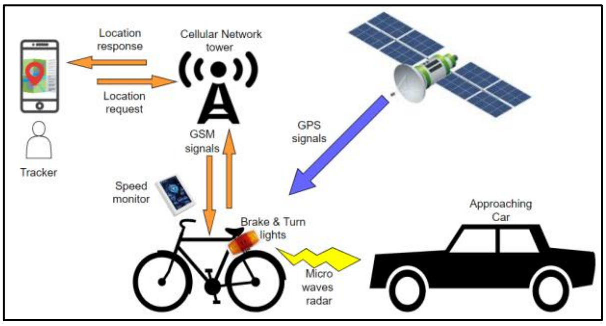

Figure 1: Overview block diagram

Three Arduino UNO boards are utilized. One is to monitor bicycle speed based on GPS module reading, shares the bicycle location, and controls the red taillight. While the second Arduino UNO board checks the gyroscope values to control the turn signal lights based on the handlebar steering direction. The third Arduino UNO board detects vehicles behind the bicycle.

Bicycle performance system

The bicycle speed monitoring relying on GPS module readings. Where the speed values are displayed via the LCD screen on the handlebar. The TinyGPS++ library is employed to extract the speed values from the NEO-6M GPS module which apply Doppler-shift-based velocity calculations. This technique is more accurate than positional difference [23]. By default, the Arduino UNO board reads the speed in meters per second and converts it to kilometers per hour using the following equation:

$$\text{Speed (km / h)} = \text{Speed (m / s)} \times 3.6 \quad (1)$$

Kilometers per hour speed unit is more understandable for riders and assists them to manage their speed. The proposed system reads the speed value every one second to avoid error margins and easily convert the speed unit. After that, the speed is displayed on the LCD screen. See figure 2.

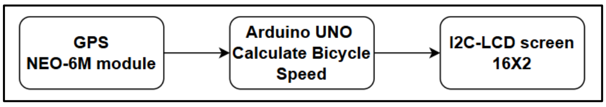

Figure 2: Speed monitoring system block diagram

Figure 3 shows the speed monitoring algorithm flowchart. The GPS data is checked to see whether it is updated or not. If yes, the function *gps.speed.mps()* extracts the speed from the GPS module directly. Next, convert the speed unit and use the speed value smoothing step before displaying it. The smoothing step is used to prevent any noisy reading or sudden jump in speed value.

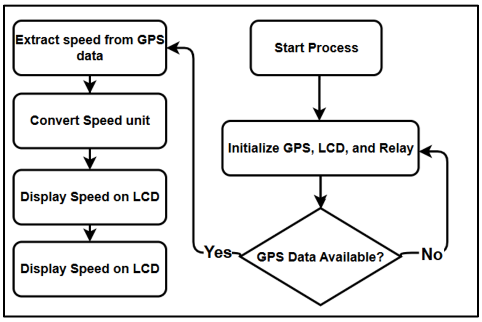

Figure 3: Speed monitoring system flowchart

Bicycle location tracking system

The real-time bicycle location is shared using GPS and GSM modules. Whenever the tracker sends the find text message "get location" to the tracking system, the Arduino sends back the location as a URL link format to the tracker phone via an SMS message. The tracker clicks that link to go directly to the Google Maps webpage to observe the exact bicycle location. Figure 4 presents the system concept. Where, Arduino continuously reads the GPS data, and whenever it receives the find SMS message, it assigns the latest location and sends it to the tracker. Obviously, the communication between the tracker and the bicycle has been done via the mobile communication networks (cellular networks).

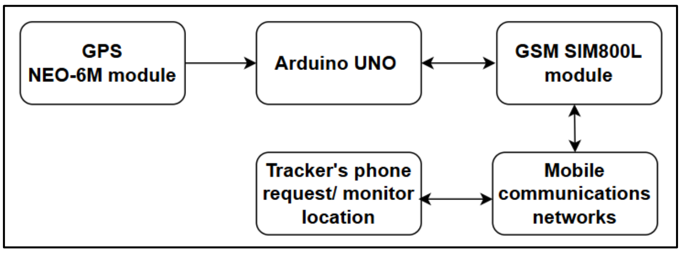

Figure 4: Location tracking system block diagram

The location SMS message is structured to be a URL link which includes the base URL of the Google Maps web service https://maps.google.com/maps?q=loc: with the latitude and longitude values in decimal degrees format.

The tracking system software algorithm is presented in figure 5. The Arduino waiting to receive an SMS. Then, it checks whether it equals "get location" or not. If yes and the GPS value is available, it sends back the location. Otherwise, it sends the error message, "Unable to get location. GPS signal not available".

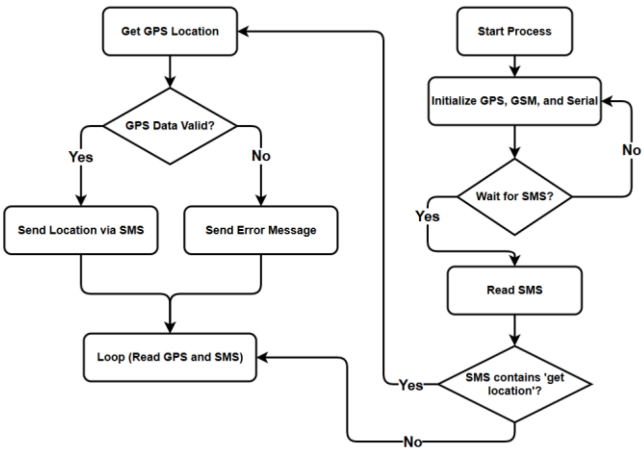

Figure 5: Location tracking system flowchart

Bicycle safety system:

a. Rear light control system

Based on [2], the flashing light improves the bicycle's visibility during daytime and nighttime, which makes bicyclists easy to be recognized and detected by other road users. Additionally, the flashing light makes other drivers able to estimate the distance between their vehicles and the bicycle in front of them [8]. Furthermore, the flashing brake light makes the drivers respond faster than the steady brake light [7]. Consequently, in this proposed system, the rear red light has two different flashing modes. One during the normal situation and the other when the bicyclist lowered the speed.

The Arduino UNO continuously reads the speed values and compares the current state versus the previous state of speed. If the previous speed is higher than the current speed with a certain value, this means the rider hits the brakes. So, the Arduino sends a command to a 5V relay to blink the red backlight with intervals of 250 milliseconds instead of the intervals of 500 milliseconds. See figure 6 and 7.

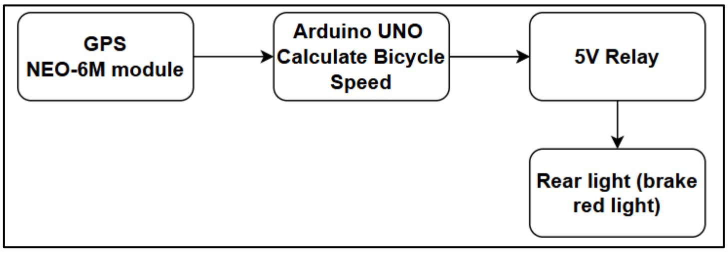

Figure 6: Rear light controlling system Block diagram

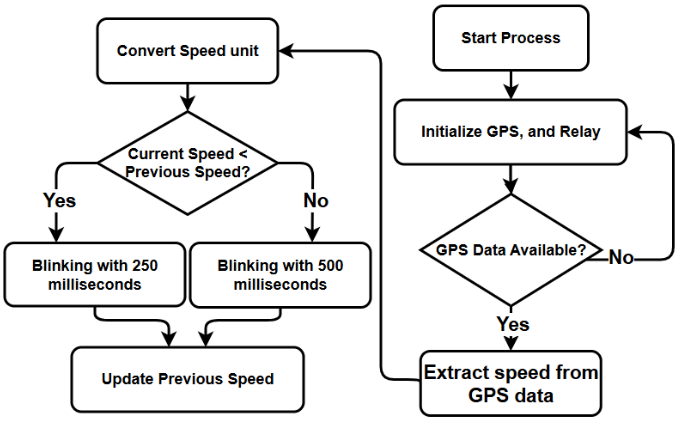

Figure 7: Rear light controlling flowchart

b. Hardware implementation

The hardware implementation of the speed monitoring, location tracking, and rear light controlling systems are presented in figures 8 and 9. Those three systems are managed by one Arduino UNO board because they depend on the GPS module.

Two batteries are utilized in this implementation. A 9V battery powers the Arduino UNO board only, while the second (3.7 Li-ion battery) powers the GSM, GPS, LCD screen, and the rear light. The power supply of the Arduino board is separated from the power supply of the rest of the components to avoid harmful factors such as power overload, voltage drops, and preventing any effect that may occur during the components operation. It is very significant to make a common ground for the whole system, which means that all the components' ground pins (GND) are connected together with the ground pins (negative polar) of the two power sources.

The GPS and the GSM modules communicate with the Arduino UNO board via the UART serial protocol. Whereas, the I2C-LCD communicates with the Arduino board via the I2C serial protocol. Finally, the rear light is connected to the 5V relay on the NO (Normally Open) pin.

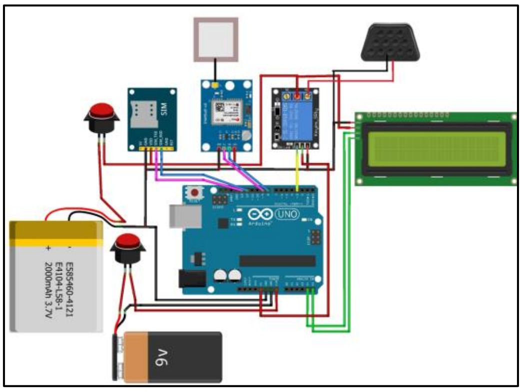

Figure 8 Wiring diagram of bicycle speed monitoring, location tracking, and rear light controlling systems

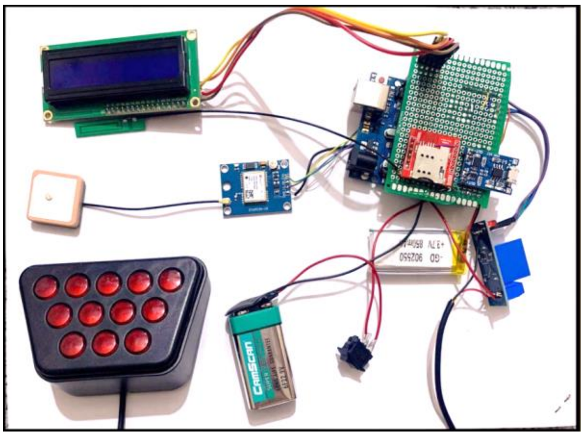

Figure 9: Hardware implementation of bicycle speed monitoring, location tracking, and rear light control systems

c. Turn signals control system

The gyroscope MPU-6050 sensor is employed in this system (See figure 10) to detect the handlebar rotational motion which is used to activate an arrow-shaped LED according to motion direction. This approach does not require any physical activity from the rider to control the turn signal light, and it immediately responds to the turning actions to enhance the safety communication with backward drivers.

The gyroscope and the Arduino UNO board installed inside a plastic box on the center of the bicycle handlebar. The orientation of the gyroscope MPU-6050 module is shown in figure 11. Where the Z-axis is perpendicular to the ground to detect the wanted rotation angles, and ignore the X and Y axes values.

Figure 10: MPU-6050 module

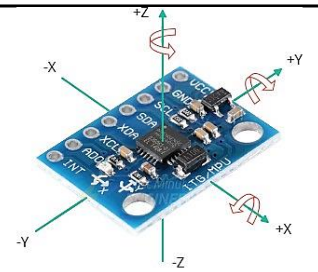

Figure 11: Gyroscope orientations

The Arduino reads gyro-Z values continuously and checks whether they cross a predefined threshold or not. (-+20) degrees per second is the threshold in this proposed system. When the gyro-Z > +20, means the handlebar is turned to the right. While when gyro-Z < -20, means it is turned to the left. According to the direction, an arrow-shaped LED blinks for 15 seconds with intervals of 500 milliseconds (half a second) whenever the threshold is crossed. Otherwise, the Arduino keeps the turn signals OFF. See figures 12 and 13.

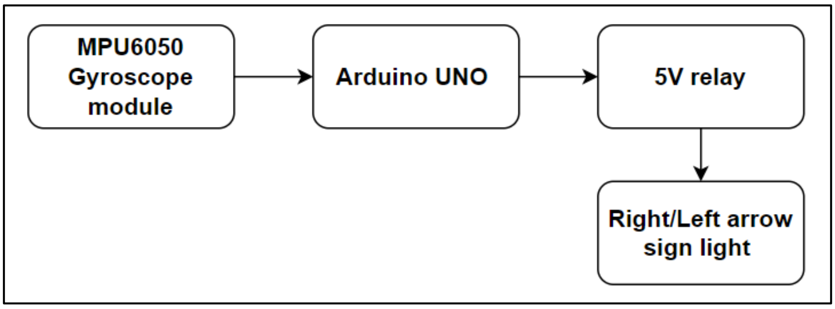

Figure 12: Turn signals control system block diagram

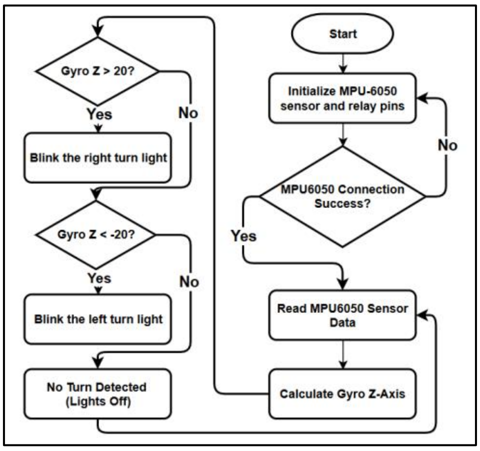

Figure 13 Turn signals control system flowchart

The system hardware implementation is presented in figure 14. The MPU6050 operates with a voltage (2.4V to 3.5V). So, an AMS1117 voltage regulator is needed to achieve 3.3V from the 3.7V Li-ion battery. The MPU6050 communicates with the Arduino via the I2C serial protocol. Reference ground for the whole system is employed because there is more than one power source in the system. The turn signal LEDs are connected with the relay on the NO (normally open) pin to be controlled via Arduino and receive power from the 3.7V Li-ion battery.

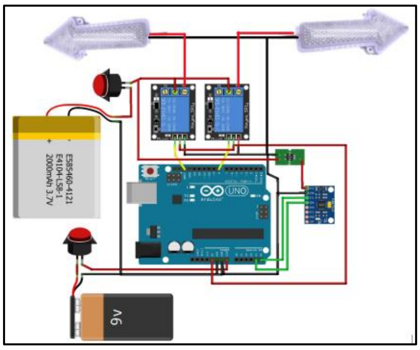

Figure 14: Turn signals control system wiring diagram

d. Rear radar motion detection system

The microwave radar motion detection system is for the bicycle backward protection. The RCWL-0516 detects motion within seven meters behind the bicycle and the Arduino alerts via a buzzer (warning sound) to make the rider pay attention about any vehicle approaching within that range. See figure 15.

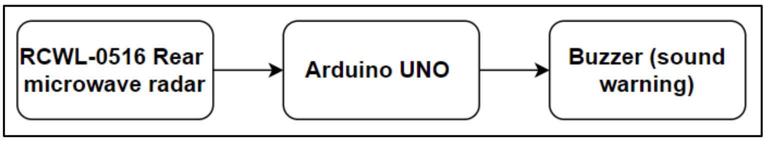

Figure 15: Block diagram of rear radar motion detection system

The algorithm of the system is explained through figure 17. The sensor gives HIGH signal when detects motion. So, the Arduino activates a sonic alarm for five seconds, then repeats the checking process.

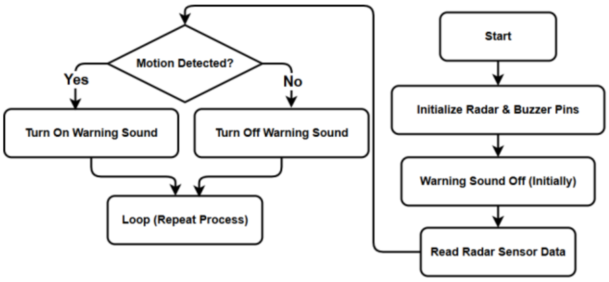

Figure 16: Rear radar motion detection system flowchart

The RCWL-0516 sensor can be connected to any GIOP of Arduino UNO board. In this system, the Arduino powers the components because they are not harmful loads. See figure 17.

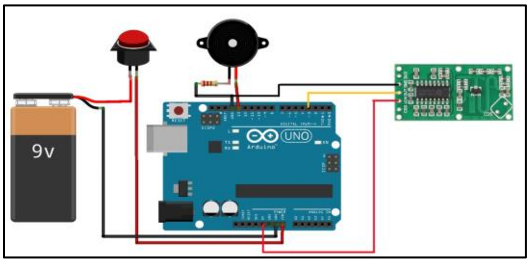

Figure 17: Radar motion detection system wiring diagram

The system hardware implementation is illustrated by figures 18 and 19. By default, the RCWL-0516 radar sensor detects motion with an angular range of 360 degrees. This range is not useful in this application, so an ironic cubic box made of 2mm-thick plate is employed to block the unwanted radar microwaves directions and focus them on an acute angle that covers the bicycle backward only. This cubic box is mounted behind the bicycle seat.

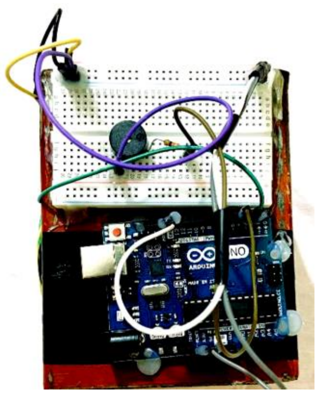

Figure 18: Top-view of rear radar system

Figure 19: Back-view of rear radar system that faces the backward vehicles

3. RESULTS AND DISCUSSION

Bicycle performance system results

The bicycle speed is displayed on the LCD screen in kilometers per hour and the value is updated every one second. The Doppler-shift speed monitoring technique that is applied by the GPS to calculate the speed has many advantages. It is more accurate than positional changes in high and slow speeds. It provides real-time measurements, which means it does not require a successful position update to measure the speed. Therefore, it is very efficient for responsive speed change.

The speed accuracy may be influenced by whether the GPS module is facing the sky or not. Second, satellite signal quality and strength are affected by environmental conditions such as buildings, trees, tunnels, heavy rain, and thick clouds. Therefore, the speed results in open areas are more accurate than in dense urban or mountainous areas. Furthermore, the GPS module has a positioning error limit. For example, the NEO-6M module has an error around of +/- 0.1 m/s, which is acceptable for this kind of application.

The LCD screen can be seen during the daytime unless it faces direct sunlight. So, using a windshield can solve it. Figure 20 shows a plastic box with a GPS antenna and an LCD screen that displays the speed. This box is mounted on the handlebar in front of the cyclist.

Figure 20: A plastic box includes two Arduino UNO boards, GPS, GSM modules and MPU-6050 sensor

Bicycle tracking system results

The tracking system works well to share the real-time bicycle location whenever the tracker sends the find SMS message "get location" text to the bicycle. The find text should be spelled precisely, otherwise an error message is sent back to the tracker. Thus, this text is written in the code as a condition. The location message is formatted as a URL link that includes the base link of Google Maps and the latitude and longitude of the location, so the tracker locates the bicycle by clicking the link only. Figures 21 and 22 show the tracker phone sending SMS and getting the bicycle location each time. So, the tracker can choose the "directions" option on the Google Maps to reach that pinpoint.

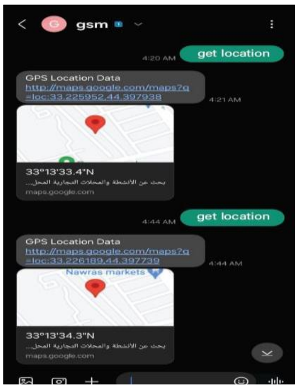

Figure 21: Tracker phone sending SMS to

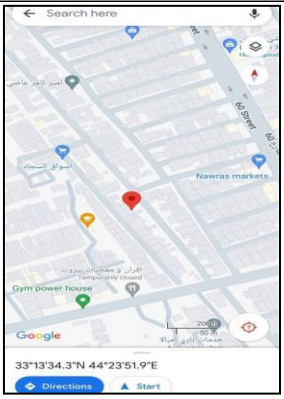

Figure 22: Tracker phone Google maps

Table 1 shows an experimental tracking cycling path that starts from the college of engineering campus to the University of Information Technology and Communications main campus in Baghdad, Iraq. The column on the left includes the URL links that were received from the bicycle during the trip, while the right column is the extracted latitude and longitude values from those links. These values are copied and pasted in a .txt or .csv file, which is uploaded to "GPS Visualizer" a free online platform to trace the cycling path. See figure 23. This platform draws the path automatically based on the uploaded file values.

Table 1: URL links of the bicycle locations and the latitude and longitude values

Location messages on the tracker's phone	Latitude and longitude (decimal degrees format)
https://maps.google.com/maps?q=loc:33.319568,44.365573	33.319568, 44.365573
https://maps.google.com/maps?q=loc:33.317194,44.370667	33.317194, 44.370667
https://maps.google.com/maps?q=loc:33.328060,44.399777	33.328060, 44.399777
https://maps.google.com/maps?q=loc:33.328500,44.415087	33.328500, 44.415087
https://maps.google.com/maps?q=loc:33.312520,44.427764	33.328500, 44.415087

Figure 23: Trace the cycling path of the experimental trip

The other free online tool that can draw the cycling path is “Google MyMaps” but this platform does not draw automatically; instead, it shows all the pinpoints that were included in the uploaded file, and users have to link them manually. Users can add photos of those places and save the edited map on Google Drive for documentation purposes.

Cycling path distance measurement is done manually by both platforms, “GPS Visualizer” and “Google MyMaps”. Therefore, as much as the tracker gets locations, the cycling path becomes more accurate and the distance value as well. See figure 24.

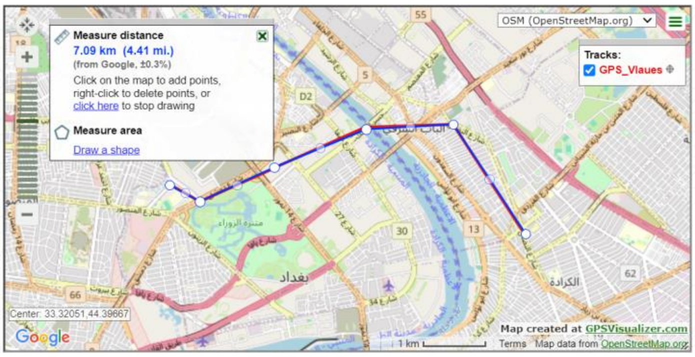

Figure 24: Cycling path distance measurement

Bicycle safety system results:

a. Rear red light automatic activation

This light is mounted behind the seat, and it continuously blinks within an interval of 500 milliseconds (half a second) to boost the bicycle’s visibility for people who are behind in day and night times. However, when the rider slows down the speed, this light blinks with a 250 millisecond intervals, which means faster than the normal status to let drivers easily estimate the distance between them and the bicycle to avoid backward accidents.

b. Turn signals automatic activation

When the gyroscope value crosses the threshold (-/+20 degrees/second), the turn signals in figures 25 and 26 blink for fifteen seconds with intervals of 500 milliseconds (each half second). This approach eliminates the rider's physical interaction to activate the turn signals to keep his/her focus on the road only. Turn signals have a vital role in informing people who are behind the bicycle about the bicycle motion direction. This improves the communication between the bicyclist and other road users.

Figure 25: Left turn signal

Figure 26: Right turn signal

c. Rear radar motion detection

The ironic shield, in figure18 and 19, works very well in blocking the microwaves to focus them towards the bicycle backward direction only to detect motions. The microwave's range is seven meters, which is good enough to warn cyclists about the approaching vehicles from behind. This system provides a safe buffering distance for cyclists from behind. However, in case of very high speed vehicles, this radar system may not help effectively.

4. CONCLUSION

To sum up, this project provides promising solutions to make the traditional bikes face fewer accidents on roads with less physical interaction from the riders. It proposes three systems based on Arduino UNO boards. First, the speed monitoring system relies on the GPS module to extract the speed value and display it on the LCD in front of the rider. Second, the location tracking system transmits the bicycle location whenever it receives a find text message. Third, the safety system includes three subsystems: a rear red light controlling improves the bicycle visibility on roads and avoids backwards accidents. A turn signals controlling informs other road users about the bicycle turn direction. Finally, the rear radar detects vehicles within seven meters behind the bicycle to warn the cyclist about them.

Future works

A dynamo for electrical generation can be utilized to charge a central battery to obtain a self-powered system. The rear radar motion detection does not tell the distance, so adding ultrasonic sensor such as HC-SR04 or LiDAR can be a promising solution. Finally, the GPS, in addition to a data logger, can save all the bicycle locations on an SD card, which can be uploaded to any mapping platform to trace the whole cycling path.

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