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Board 103: Solar-Powered Car Speed Radar Measurement, Display, and Logging System

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Solar Powered Car Speed Radar Measurement, Display, and Logging System

Abstract

Studies have shown that there is a 10% fatality rate when a pedestrian is struck by a vehicle moving at the speed of 20 (mph), and the rate scales up to 90% at the speed of 40 (mph). Moreover, the residential areas with radar speed monitors are shown to be safer in terms of accident probability. Motivated by these statistics, in this National Science Foundation sponsored senior design project a speed radar system is designed and developed. The components, functionalities, and objectives of the project are listed as follows: (i) A camera will detect and identify a vehicle and distinguish it from other objects; (ii) a radar sensor will measure the speed of the vehicle; (iii) a microprocessor (Raspberry Pi) will acquire the speed data, send it to the display, and analyze and log it in a server; and (iv) a stand-alone solar Photovoltaic system will provide electrical power to and guarantee the continuous operation of the entire system. This senior design project was conducted by a group of undergraduate students in the electrical and computer engineering technology program at New Jersey Institute of Technology.

Introduction

The implementation of solar-based car speed display systems aims to reduce a driver's speed in residential or other areas. Some studies have shown that for more than two decades, speeding has led to approximately one-third of all motor vehicle fatalities [1]. In 2020, there were 11,258 speeding-related deaths, which accounted for 29% of all traffic fatalities [2]. This fatality rate averages out to over 30 people per day. The history of fatality numbers and rates for the past two decades is depicted in Figure 1 [2].

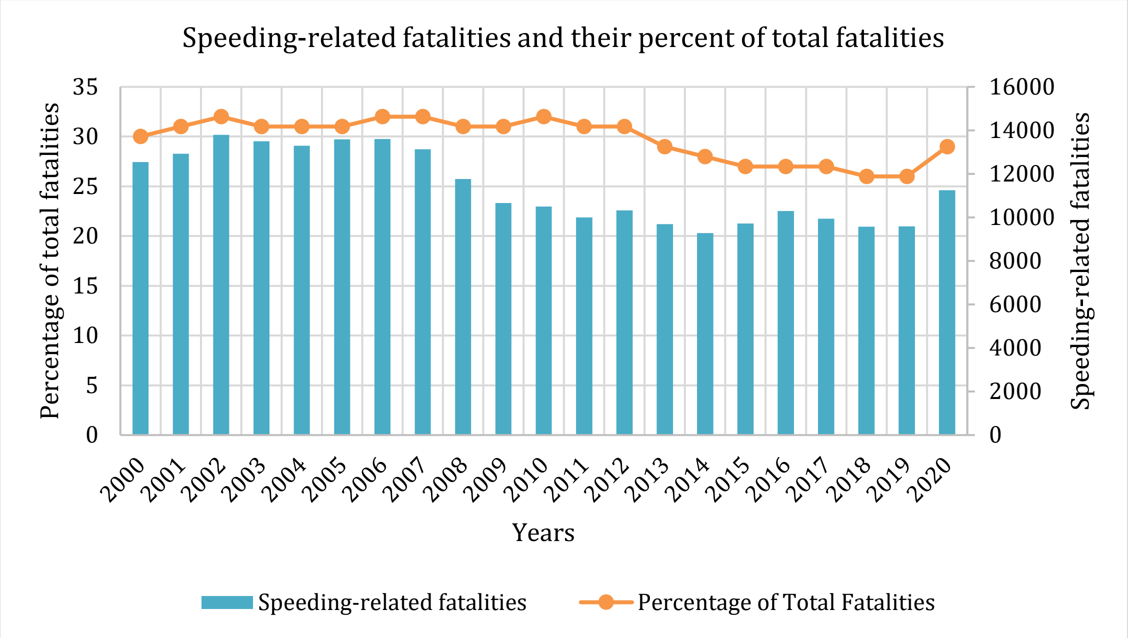


Figure 1. History of fatality numbers and rated for the past decade [2].

Research shows that car speed display systems help to reduce a driver's speed. A study in the town of Amherst, New Hampshire, indicated that 80% of speeders slowed down by 10-20% when they saw their speed on the sign [3]. A similar study conducted by the Center for Disease Control and Prevention indicated that the areas with the speed cameras saw a decrease in the drivers' mean speed [4]. They also conducted a phone survey of the drivers within the community and found that 95% of the drivers were aware of the cameras and 76% of them reduced their speed. One such example of a speed radar system is patented by Eliot S. Gerber. Their design utilizes a sign that displays the license plate number, owner's name, and the vehicle's speed [5]. It also uses a database to store the license plate numbers, owner's name, and make and model of the vehicle. Similar systems were patented by James A. Fowler and Leon O. Stenneth [6], and Carl Kupersmit [7].

This paper presents the design, development, and programming of a stand-alone solar-powered car speed radar system for real-world application. The system includes a Wireless Notecarrier Pi Hat, a Wireless Notecard, a camera, a radar sensor, two LED matrices, a LED matrix bonnet, and a Raspberry Pi 4. The Raspberry Pi 4 is used to run Python 3 to interface and control each of the components. As a vehicle approaches the system, an object detection algorithm is used by the camera to detect the vehicle and determine whether it is a car, bus, or truck. Once a vehicle is detected, the doppler radar sensor measures its speed. Then, the measured speed and the speed limit are displayed separately on the two LED matrices. Finally, the Wireless Notecard is used to provide a cellular service to send the type and speed of the vehicle to a database. The required electrical power is provided by a stand-alone Photovoltaic (PV) system that includes two solar panels, a charge controller, a battery, and two DC-DC converters. The solar panels, connected in parallel, supply DC power to the charge controller. The charge controller regulates the input from the solar panels to charge the battery, while preventing overcharging, and supplies DC power to the electronic components. Using two converters, the output electricity from the charge controller is converted to 5 (V) and 10 (A) electricity to power the Raspberry Pi and the two LED matrices. When the system is in operation, the solar panels power the system during the day, while the battery powers the system at night.

Electrical Components

In this section, the electrical components used in this project are explained in detail, which are demonstrated in Figure 2.

<u>100W 20V Compact Design High Efficiency Solar Panels (Figure 2-(a)):</u> These solar panels are chosen for their size and high efficiency. The dimensions are 28.54 × 27.76 × 1.18 (in). The weight of one panel is 13 (lb). The mounting brackets for these solar panels allow for easy adjustments to their angle. A 2.5 (ft) cable with MC4 outdoor connectors, which is a reliable connection with weather tight seal, is pre-attached for quick assembly. The main electrical specifications of the solar panels are as follows:

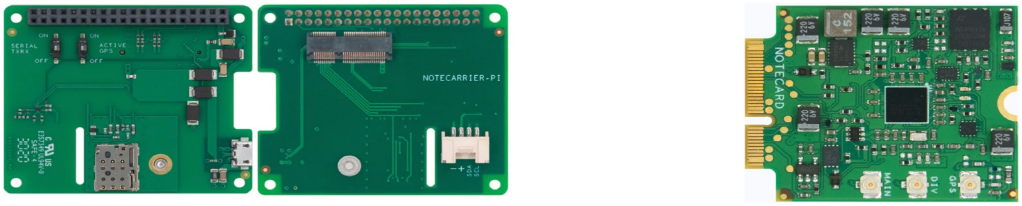
- Maximum Power Output: 100 (W)
- Voltage MPP (Vmp): 19.06 (V); Current MPP (Imp): 5.26 (A)
- Voltage Open Circuit (Voc): 21.82 (V)
- Short Circuit Current (Isc): 5.55 (A)

(a) Solar panel

(b) Charge controller

(c) Battery

(d) Converter



(e) Wireless Notecarrier Pi Hat (front and back)

(f) Wireless Notecard

(g) Camera

(h) Radar Sensor

(i) Matrix Display (front and back)

(j) Bonnet

(k) Raspberry Pi

Figure 2. Electrical components.

12V/24V 30A Solar Charge Controller (Figure 2-(b)): This charge controller is compatible with 12 (V) and 24 (V) systems and has a discharge current of 30 (A). It has a LCD display that indicates the status and the values of solar panel voltage, battery voltage, and current to the battery. The charge controller also includes a 3-stage PWM regulation charging mechanism including direct, lifting, and floating charge modes. This allows the charge controller to provide efficient and fast charging, while it effectively prolongs the service life of the battery. It also has built-in over-current, short-circuit, reverse-connection, and open-circuit protections.

ECI Power 12V 10Ah Lithium LiFePO4 Deep Cycle Battery (Figure 2-(c)): This battery utilizes UL1642 listed LiFePO4 Grade-A cells. It provides a minimum of 3500 cycles at 80% Depth of Discharge (DOD) and a high-performance longevity with a maximum of 7000 cycles at 50% DOD. It features a built-in Battery Management System (BMS) to protect it from overcharging, deep discharging, overloading, overheating, and short-circuits. The main specifications of the battery are as follows:

- Nominal Voltage: 12.8 (V); Charging Voltage: 14.4 ± 0.2 (V)
- Rated Capacity: 10 (Ah) at 25°C
- Dimensions: 6 × 2.6 × 3.7 (in)
- Weight: 2.35 (lb)
- Maximum Continuous Discharge Current: 10 (A)
- Maximum Permanent Discharge Current: 15(A) in 5 (sec)
- Maximum Continuous Charge Current: 5 (A)
- Operating Temperature: Discharge: -4 °F to 140°F; Charge: 32°F to 140°F

12V/24V to 5V 10A DC-DC Converter (Figure 2-(d)): This converter is used to convert the output voltage of the charge controller (from the solar panels and battery) to the 5 (V) and 10 (A) electricity needed to power the Raspberry Pi 4 and the two LED matrices. The converter also features over-voltage, over-current, over-temperature, and short-circuit protection.

Blues Wireless Notecarrier Pi Hat (Figure 2-(e)): The Notecarrier Pi Hat is designed for drop-in development with a Raspberry Pi and must be powered by a Raspberry Pi or other compatible single-board microprocessors. It features a pre-soldered stackable 40-pin header for plugging directly into the Raspberry Pi. It also features a Notecard edge connector socket and a mounting screw receptacle. The DIP switches on the bottom of the Notecarrier Pi Hat allow the configuration of diagnostic serial port, attention pin, and active GPS support. The Notecarrier Pi Hat also requires user provided U.FL cellular/Wi-Fi and optional U.FL active GPS antennas.

Blues Wireless Notecard (Figure 2-(f)): The Notecard offers 500 (MB) of cellular connectivity and global cellular over LTE-M, NB-IoT, or Cat-1. It features low-power hardware and power-conscious firmware, and is embedded with onboard M.2 Key E connector or interfaces with a companion board.

Raspberry Pi Camera Module V2 (Figure 2-(g)): The camera is a Sony IMX219 8-megapixel sensor, which provides high-definition videos and photos. It supports 1080p30, 720p60, and VGA90 video modes, as well as still capture. The camera attaches to the CSI Raspberry Pi camera port via the 15 (cm) ribbon cable.

OmniPreSense OPS243-A-CW-WB Doppler Radar Sensor (Figure 2-(h)): This radar sensor provides motion detection, and speed and direction measurement. The radar signal processing is all done on board, and the processed data is reported by a simple API. The radar also allows for flexible control over the reporting format, sample rate, and module power levels. The data can be communicated over Wi-Fi/Bluetooth or the optional USB interface. The main features include:

- Detection Range: 3-328’
- Speed Reporting in Excess of 138 (mph)
- Speed Accuracy: 0.5%
- Direction Reporting (Inbound/Outbound)
- Narrow 20° Beam Width (-3 (dBm))
- Active Power: 2 (W); Idle Power: 0.9 (W)
- Dimensions: 2.95 × 3.78 × 0.47 (in), Weight: 15 (g)

Adafruit 64×64 LED Matrix Panel (Figure 2-(i)): The LED matrix consists of 4,096 RGB LEDs arranged in a 64×64 grid at a 2.5 (mm) pitch. The matrix uses a non-standard 5-address multiplexing system unlike the typical 4-address system. The kit for the matrix includes an IDC ribbon cable and a power cable. The main features include:

- Brightness: 2800 (cd/square meter)
- Size: 6.30 × 6.30 (in); Pitch: 0.098 (in)
- Refresh Frequency: ≥ 40 (Hz)
- Weight: 204.8 (g) only matrix panel, and 255 (g) with components

Adafruit LED Matrix Bonnet (Figure 2-(j)): The bonnet works on any Raspberry Pi with a 40-pin GPIO header. It allows for power protection circuitry when a 5 (V) and 4 (A) wall adapter is plugged into the bonnet. It features onboard level shifters that convert the Raspberry Pi’s 3.3 (V) to 5.0 (V) logic for glitch free matrix driving. The Raspberry Pi, however, is not powerful enough to power the LED matrices, which is why the DC-DC converters are needed. In order to determine the power supply need, the width of the LED matrix (64) needs to be multiplied by 0.12 (A), which gives a total of 7.68 (A).

Raspberry Pi 4 Model B (Figure 2-(k)): This Raspberry Pi was chosen in this project due to its compatibility with the Notecard. It has 8 (GB) of LPDDR4-3200 SDRAM for data processing. The main specifications include:

- Broadcom BCM2811, Quad Core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5 (GHz)
- 2.4 (GHz) and 5.0 (GHz) IEEE 802.11ac wireless, Bluetooth 5.0, BLE Gigabit Ethernet
- Standard 40 pin GPIO header
- 2 USB 3.0 ports; 2 USB 2.0 ports
- 2 micro-HDMI ports (up to 4kp60 supported)
- 2-lane Mobile Industry Processor Interface (MIPI) Dual Sequential Ignition (DSI) display port; 4-pole stereo audio and composite video port
- 2-lane MIPI Camera Serial Interface (CSI) camera port
- 5 (V) DC via USB-C connector (minimum 3 (A))
- Operating ambient temperature: 0 - 50°C

Mechanical Structure Design

The SolidWorks software was used to design and provide a 3D rendering of the mechanical structure. The designed structure height is 7.5 (ft), which is depicted in Figure 3-(a).

(a) (b) (c)

Figure 3. Mechanical structure: (a) SolidWorks design, (b) assembled with solar panel mounts and electrical boxes, and (c) integrated with electronics and electrical components.

The structure of the system is built on an outdoor-rated Unistrut pole. A pair of solar panel mounts and two outdoor-rated electrical boxes are mounted to the Unistrut. The two electrical boxes are connected together through a 3/4 (in) electrical conduit. The developed mechanical structure assembled with solar panel mounts and electrical boxes are demonstrated in Figure 3-(b). The structure is mounted on plywood for demonstration purposes, but ideally it would be implemented in the field by being installed into the ground. The lower electrical box is housing the battery. A custom designed 3D printed bracket is used to secure the battery while housing the radar (speed) sensor. A battery disconnect switch is also used and placed in the lower box. The upper electrical box houses the charge controller, two DC-DC converters, the Raspberry Pi, and the camera. The Raspberry Pi and camera are mounted on another custom designed 3D printed bracket, which is secured to the electrical box. The overall system integrated with electronics and electrical components is demonstrated in Figure 3-(c).

Electronics and Electrical Structure Design

The solar panels are connected in parallel and to the charge controller and the battery. The charge controller's load terminal is connected to the two parallel DC-DC converters. The first converter feeds the Raspberry Pi and the second one feeds the two LED matrices. The wiring diagram is shown in Figure 4, in which the power source and supply are highlighted in red.

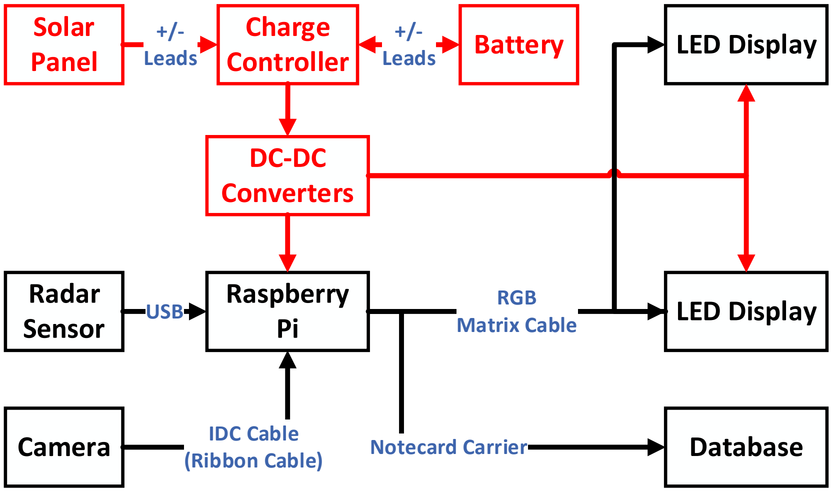
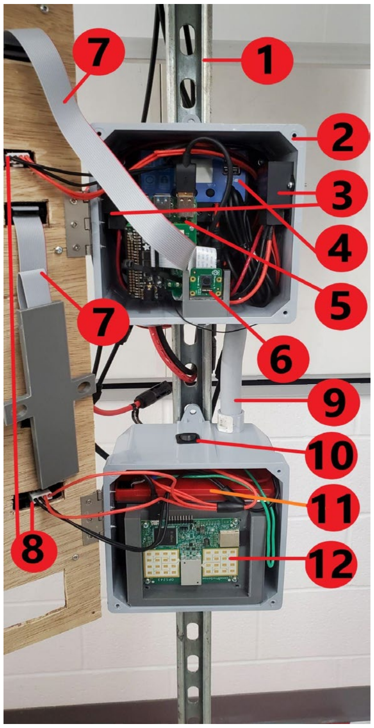


Figure 4. Wiring diagram (power source and supply are highlighted in red).

The detailed implementation and integration of electronics and electrical components is demonstrated in Figure 5.



1. **Unistrut**
2. **Electrical Box**
3. **DC-DC Converter**
4. **Charge Controller**
5. **Raspberry Pi**
6. **Camera**
7. **Matrix Display Cable**
8. **Matrix Power Connector**
9. **¾” Conduit**
10. **Battery Disconnect**
11. **Battery**
12. **Radar Sensor**

Figure 5. Implementation and integration of electronics and electrical components.

Calculating the total power requirement is critical for designing the stand-alone PV system. The total power is determined based on the power consumption of Raspberry Pi, radar, camera, LED matrices, LED bonnet, and Notecard.

$$\begin{aligned}\text{Total Power} &= \text{Raspberry Pi} + \text{radar} + \text{camera} + 2 \times \text{LED matrix} + \text{LED Bonnet} + \text{Notecard}\\ &= 6.4\ (\text{W}) + 1.7\ (\text{W}) + 10\ (\text{W}) + 40\ (\text{W}) + 20\ (\text{W}) + 10\ (\text{W}) = 88.1\ (\text{W})\end{aligned}$$

The solar PV system in this project requires a minimum power generation capacity that exceeds 90 (W), and the excess power is used to charge the battery throughout the day. Two 100 (W) compact size solar panels are used in parallel, which allow continuous generation of electrical power and sufficient amount of light captured throughout the day. The two panels make up a maximum power of 200 (W). Assuming a 50% efficiency due to geographical and ambient conditions, they would produce a net power of 100 (W), which is sufficient for powering the load and charging the battery. However, the power efficiency is normally more than 50%, which makes the stand-along solar PV system more reliable. To prevent overcharging of the battery and preserve its health, a charge controller is utilized to disconnect the PV panels when the battery is fully charged and reconnect them when the battery is discharged.

Software Development

The top-level data flow diagram is shown in Figure 6, in which the information is transferred from the input into the processing unit, and then to the output.

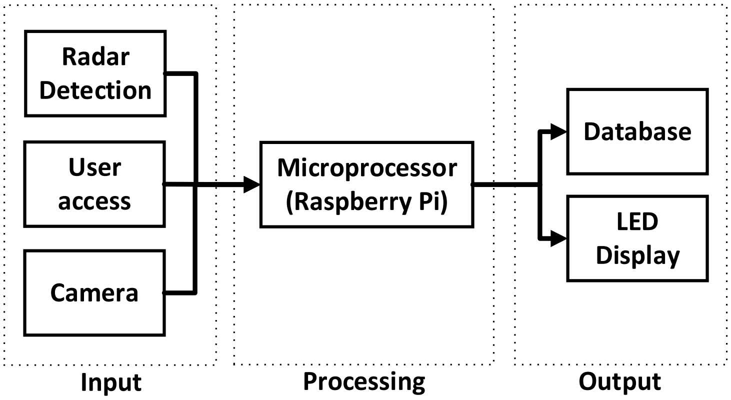


Figure 6. Data flow diagram.

The developed algorithm is demonstrated in Figure 7. The code begins by importing libraries and declaring variables. Then, the algorithm waits for a vehicle to be detected by the camera. Once a vehicle is detected and its type is identified, its speed is measured by the radar sensor. With the vehicle speed acquired, the Raspberry Pi determines if it is over or under the speed limit, based on which it displays the speed on the LCD matrix in red or green, respectively. Moreover, the Raspberry Pi stores the type and speed of vehicle in the database.

In this project, an image processing and object detection algorithm is implemented to detect a vehicle and determine whether it is a car, bus, or truck. The Edge Impulse website provides a neural network (NN) based platform, which makes the creation, learning phase, and implementation of object detection algorithm simple and easy. In this platform, first the data type is set to “image”. Then, the different classes (labels) are set, which are “car”, “bus”, and “truck”. Finally, the data set is collected, and the data is labelled in order to be used for the training and testing phases of the NN. The data set includes approximately 200 images of various cars, buses, and trucks captured in a residential area. Moreover, 50 additional images from the internet were included to increase the size of the data set. The NN model is trained and tested by using 80% and 20% of the overall data set, respectively. In this project, the NN model is set to

"MobileNetV2 SSD FPN-Lite 320×320", the number of training cycles is set to 40, the learning rate is set to 0.1, and the validation (test) set size is set to 20%, which result in a precision score of 77%. The trained NN model is downloaded in a ".eim" format onto the Raspberry Pi by first installing the Edge Impulse for Linux CLI, and then giving the file path to the python code to point to the trained NN model in order to run the object detection algorithm.

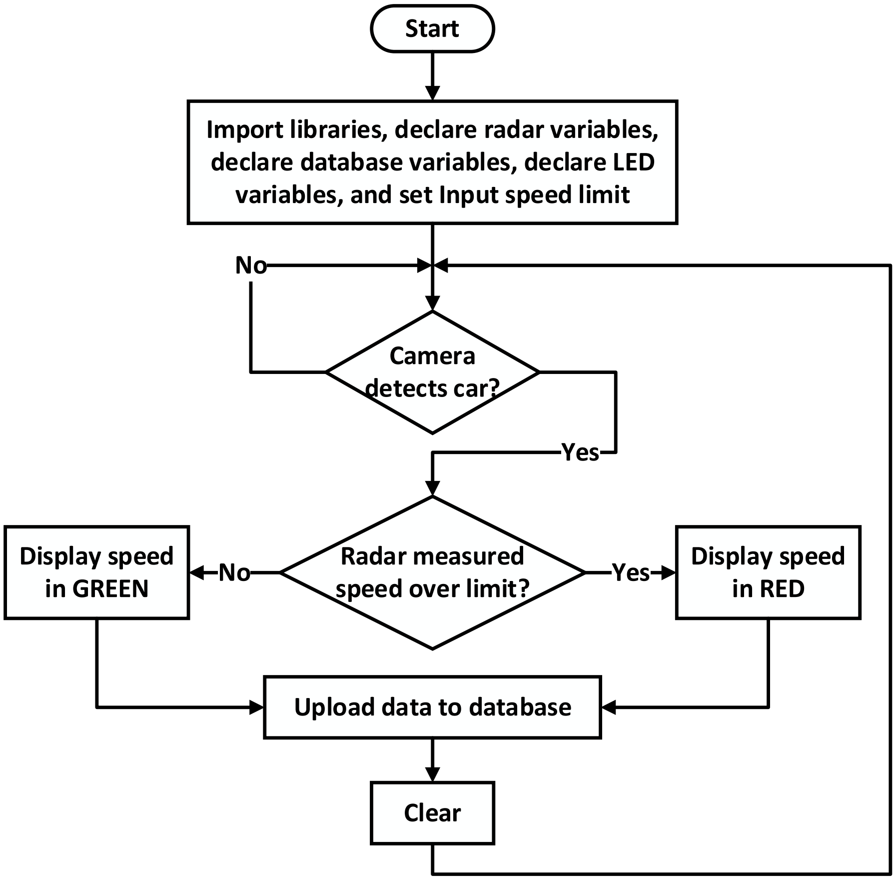


Figure 7. Developed algorithm.

For the data logging process, a cellular device called Notecard is used to transmit and receive data through a cellular connection that can be used from any geographical location in the U.S. The Notecard has many capabilities such as monitoring its own health by using a built-in heat and humidity sensor. It is capable of interacting with other sensors that are attached to the same microprocessor as it is attached to. The card can also triangulate its location with a customized geo-location tracking, and provides an option to set the location tracking as a moving or a stagnant asset. It also has the power saving capability by lowering the "heartbeat" and "periodic" settings for tracking the asset and connection to the database, respectively. In this project, the heartbeat and periodic settings significantly helped with power saving due to the fact that the entire system is powered by a stand-alone PV system. The Notecard captures data from the Raspberry Pi and transfers it to Notehub, which is a dedicated database made by the same manufacturer. The stored data in Notehub is then routed to Amazon Web Service (AWS) IoT Analytics, which is a third-party database that can analyze and visualize the data.

Conclusion

This National Science Foundation sponsored senior design project was conducted at New Jersey Institute of Technology. In this project, a solar-powered speed radar system was designed and developed. A camera detected a vehicle and identified its type by using a neural network based platform provided by the Edge Impulse website. Then, the speed of the vehicle was measured by a radar sensor. A Raspberry Pi acquired the speed data and determined if it was over or under the speed limit, based on which it displayed the speed on the LED matrix in red or green, respectively. Moreover, the Raspberry Pi used the Notecard to log the type and speed of the vehicle in Notehub and subsequently in the AWS IoT Analytics database. The entire system was powered by a stand-alone solar PV system. During the testing process, the system was slightly slower than expected with a 77% precision for object detection. In the future, the system will be improved by using a larger data set with more variety of vehicle images for training the object detection algorithm in Edge Impulse. Moreover, the python code will be modified and its structure will be optimized to allow the algorithm to run faster on the Raspberry Pi.

Acknowledgement

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