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Solar-Powered Smart Bus Shelter in UTHM Campus

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Abstract

This project involves the designing and implementation of solar-powered smart bus shelters within the UTHM campus. The current UTHM bus shelter faces challenges such as lacking real-time information, safety issues due to a lack of lighting support, and bad student experiences while waiting for a bus due to hot or bad weather. Therefore, this project seeks to enhance the students or passengers experience when they want to board on the bus and the bus shelter could provide real-time bus location display, LED lighting, and fans powered by clean solar energy. Incorporating the Internet of Things, the smart bus shelter provides the students with precise real time bus location information that enhances their safety and convenience. Besides that, the smart bus shelter also provides a messenger to notify students which bus approaches which bus shelter in order to reduce the possibility of students missing chances of boarding on the correct bus. The project helps in sustainable development by reducing energy consumption and supporting environmentally friendly public transport solutions. By extensive testing and evaluation, the performance and reliability of the prototype are validated, proving its potential in transforming the conventional bus shelter into the intelligent energy-saving system.

1. Introduction

With the population growth, the number of vehicles on the road is also increasing further leading to congestion in the city [1]. As a result, efficient and sustainable bus transport plays an important part in reducing traffic congestion, lowering pollution, and providing accessible and affordable mobility solutions for people in cities. Besides that, the field of transportation plays an important role in cities, and providing efficient, environmentally friendly public transport is important in addressing the difficulties of urbanization, traffic congestion, and environmental sustainability. However, obtaining route information on the bus is more difficult than on other modes of public transportation, this will cause the number of passengers on the bus to decrease year after year [2].

Conventional bus shelters, which serve as crucial components of public transportation infrastructure, often do not have the technology developments required to enhance the passenger experience and reduce environmental impact. Therefore, conventional bus shelters can be replaced with smart bus shelters that use IoT technology and renewable energy sources to enhance the quality of human life and protect the environment.

The Internet of Things (IoT) is a modern trend in which everyday objects such as sensors, actuators, and transceivers are envisioned to communicate with one another and with users [3]. As a result of this transformation, these objects become interconnected components of the internet, resulting in a seamless ecosystem [3]. In addition, solar energy is used in this project to provide electricity to the system. Because the sun provides us with a huge amount of power, solar energy is environmentally friendly and free. Solar energy is now a rapidly growing energy sector due to the availability of sunlight in all locations while causing no environmental harm [4].

Smart bus shelters can enhance the daily activities of communities, especially students who do not own a vehicle. However, one of the risky aspects of community bus operation is that the buses do not arrive on time. Therefore, smart bus shelters should be developed to visualize bus location data [5]. For example, the timetable should include information such as bus number, destination, and frequency of service from a specific bus stop [6]. Besides that, smart bus shelters are important in reducing anxiety while riding the bus and encouraging students to actively use the community bus [7].

In this project, a fan, LED light, real-time information, and a messenger to alert students when the bus is approaching will be designed to improve the experience of bus passengers. This can help to reduce car accidents on the UTHM campus and throughout the city because students will prefer to take the bus if they are comfortable and have a good experience.

2. Methodology

The methodology involves designing and testing a prototype of the solar-powered smart bus shelter system. The system includes solar panel, solar charge controller, sealed rechargeable battery, PIR (Passive Infrared) sensor, LDR (Light Dependent Resistor) sensor, GPS (Global Positioning System) modules, LED (Light-emitting Diode) lighting, fans, and bus tracking dashboard.

2.1 Block Diagram and Flow Chart

Figure 1 shows a solar-powered smart bus shelter system block diagram. First of all, the solar panel will obtain solar energy to charge the battery with the support of a solar charge controller. The solar charge controller is able to protect the battery by preventing the battery overcharge and powering up to the whole system. When the microcontroller ESP32-Wroom-32 Module receives electricity, it reads the input sensors, which include the PIR sensor, GPS module, and LDR sensor. If the sensors are detected or sensed, an output is produced, which may be a fan, an LED, or the real-time information screen display depending on the sensors or modules. If the sensors detect nothing, the fan or LED will be turned off to reduce the power lost. Besides that, there is a connection between ESP32-Wroom-32 Module, the cloud, the database and the mobile device. After the ESP32-Wroom-32 Module successfully connects to the internet, it will be able to communicate with the Arduino Cloud that used to display the real-time information of the bus.

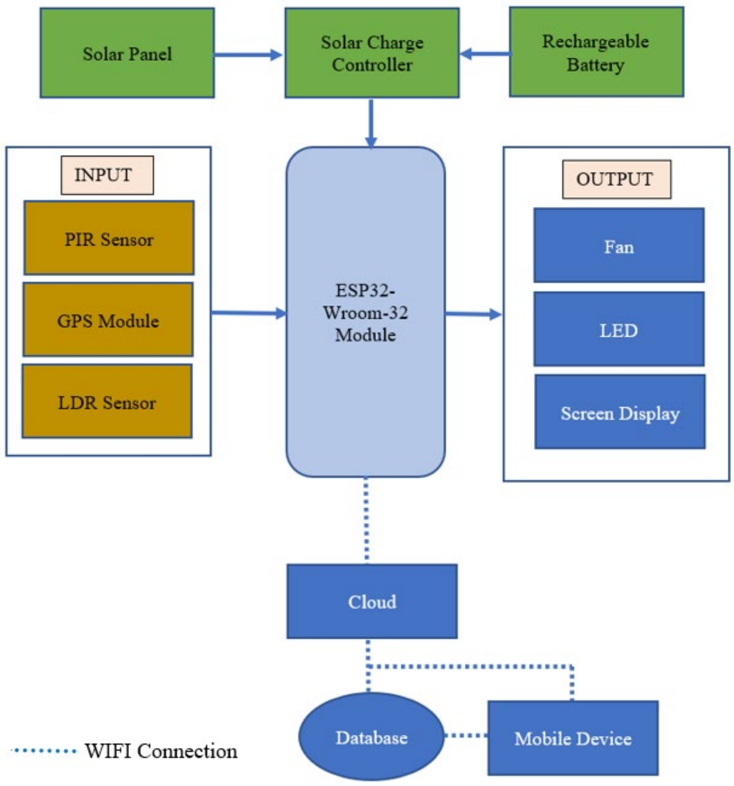

Fig. 1 *Solar-Powered Smart Bus Shelter System Block Diagram*

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Figure 2 shows the smart bus shelter's operation flow chart. First, when the ESP32 microcontroller receives power, it will check its WIFI connectivity. If the microcontroller is not connected to WIFI, it will reconnect to WIFI until successful. After the microcontroller is connected to WIFI, it will start to read three inputs: the PIR sensor, the LDR sensor, and the GPS module. The PIR sensor's output will be a fan. When the PIR sensor detects motion, the fan turns on; the fan turns off after 5 minutes if no motion is detected. Aside from that, the LDR sensor is connected to its output, which is an LED light. When the LDR sensor detects a dark environment, the LED illuminates; when a bright environment is detected, the LED turns off. Furthermore, GPS will be connected to two different buttons, and the output will be a messenger displayed on the Arduino Cloud dashboard. When a button is pressed, a message indicating that a passenger bus is approaching a specific bus shelter is transmitted to the Arduino Cloud. To prevent the same button from being activated many times and preventing message spam on messenger, the system only allows a new message to be sent when another button is pressed.

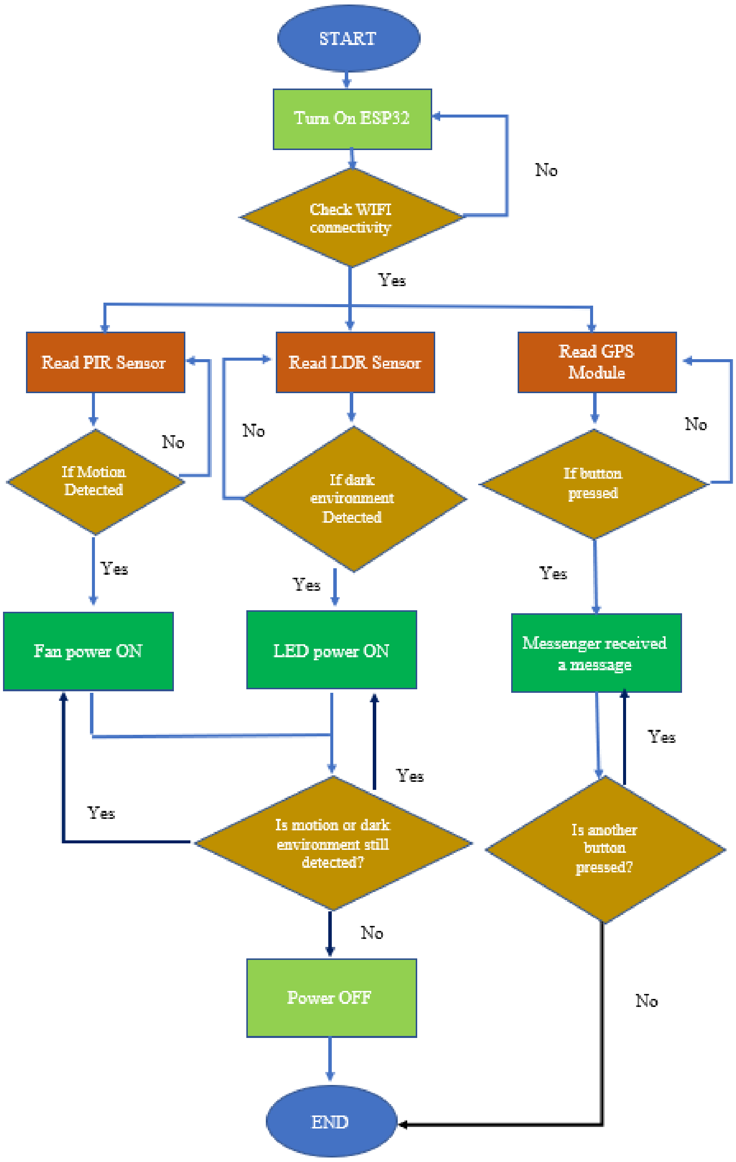

Fig. 2 *Flowchart of Smart Bus Shelter Operation System*

2.2 Software and Hardware Design

The overall connection of the Solar-Powered Smart Bus Shelter System in Proteus software is shown in Figure 3. The solar panel will provide power to the whole system, and the Arduino UNO acts as a microcontroller (for simulation). This system takes all three variables into consideration. For example, the PIR sensor detects people's motion and powers up the fan; the LDR sensor detects dark weather and powers up the LED light; and the GPS module detects location and transmits data to the virtual terminal display device to display the reading.

However, in the prototype development, the real-time location will be displayed, and a messenger will be used to alert students that the bus is approaching the specific bus shelter.

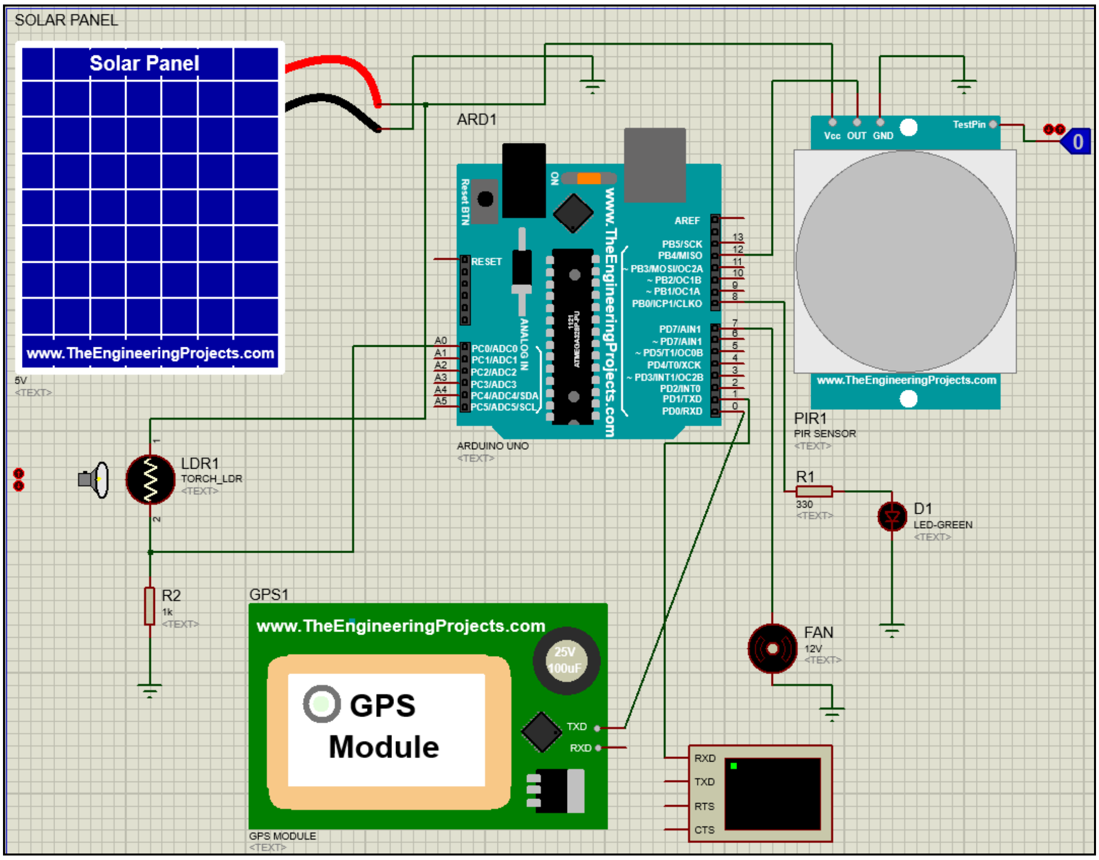

Fig. 3 *Overall connection of Solar-Powered Smart Bus Shelter System in Proteus*

Figure 4 shows the detailed connection of the Smart Bus Shelter system with the ESP32 microcontroller. Firstly, the solar panel will collect solar power and convert it into electrical energy, which will be used to charge the sealed rechargeable battery. Solar charge controllers are important devices for controlling output voltage, displaying battery usage, and preventing overcharging. Aside from that, the microcontroller ESP32-Wroom-32 Module received electricity when connected to the solar charge controller to programme the entire system. There are two inputs on the prototype: a PIR sensor and an LDR sensor. The PIR sensor's output pin connected to ESP 32's GPIO pin 12, VCC connected to the 5V pin, and GND connected to the GND pin. For example, the PIR sensor detects motion and turns on the fan via the trigger HIGH relay module. Rather than using power from the microcontroller, the relay module can give a higher voltage to turn on the fan. Another relay module was designed for future use when another LED bulb needs more electricity to power up. Furthermore, the prototype's LDR sensor will measure the intensity of light in the environment. It is connected with its output's LED, which will light up when the LDR sensor detects a dark environment. The LDR sensor's VCC is also wired to the ESP 32's 5V pin, as is its GND. However, the AO pin of the LDR sensor will be connected to GPIO pin 36 of the ESP 32, while the DO pin will be connected to GPIO pin 13 of the ESP32. Moreover, the positive pin of the LED will be connected to ESP 32's GPIO pin 18 across a resistor. Moreover, the relay module is set to trigger HIGH mode, the DC+ pin is connected to the ESP 32's 5V pin, the DC- pin is connected to GND, the input pin is connected to the ESP 32's GPIO pin 25, the NO (Normally Open) pin is connected to the positive wire that is linked with the fan, and the COM (Common terminal for output) pin is connected to the positive wire that is linked with the USB.

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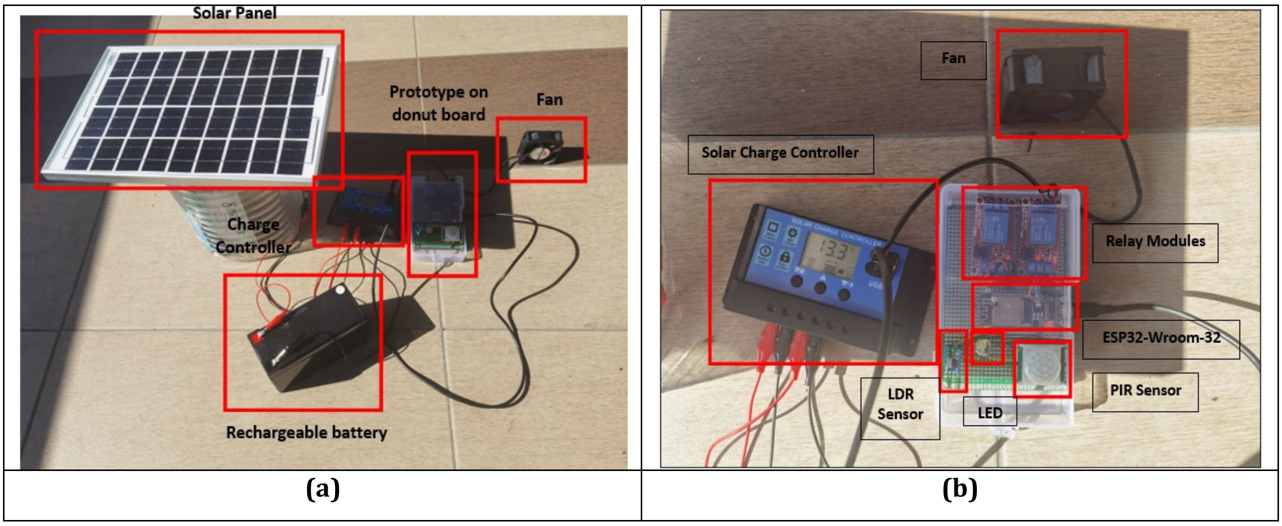

Fig. 4 *Prototype system that placed at bus shelter (a) Overall prototype connection; (b) Prototype system on donut board*

Figure 5 shows two different ESP32-Wroom-32 microcontrollers connected to a GPS module that is installed inside the bus to send real-time location information to a screen display placed at the bus shelter with the same design. For the detailed connection, the GPS module's RX pin connected to GPIO pin 22 of the ESP 32, and the GPS module's TX pin connected to GPIO pin 21. Another two pins on the GPS module, VCC and GND, are connected to the ESP 32's 5V and GND, respectively. Furthermore, other ESP 32 GPIO pins are linked to the button switch's positive pin according to the requirement (one button switch is required for representing one bus shelter). In this project, two button switches are used to test the prototype's functionality. Aside from that, all of the button switches' negative pins will be connected to the GND pin of the ESP 32.

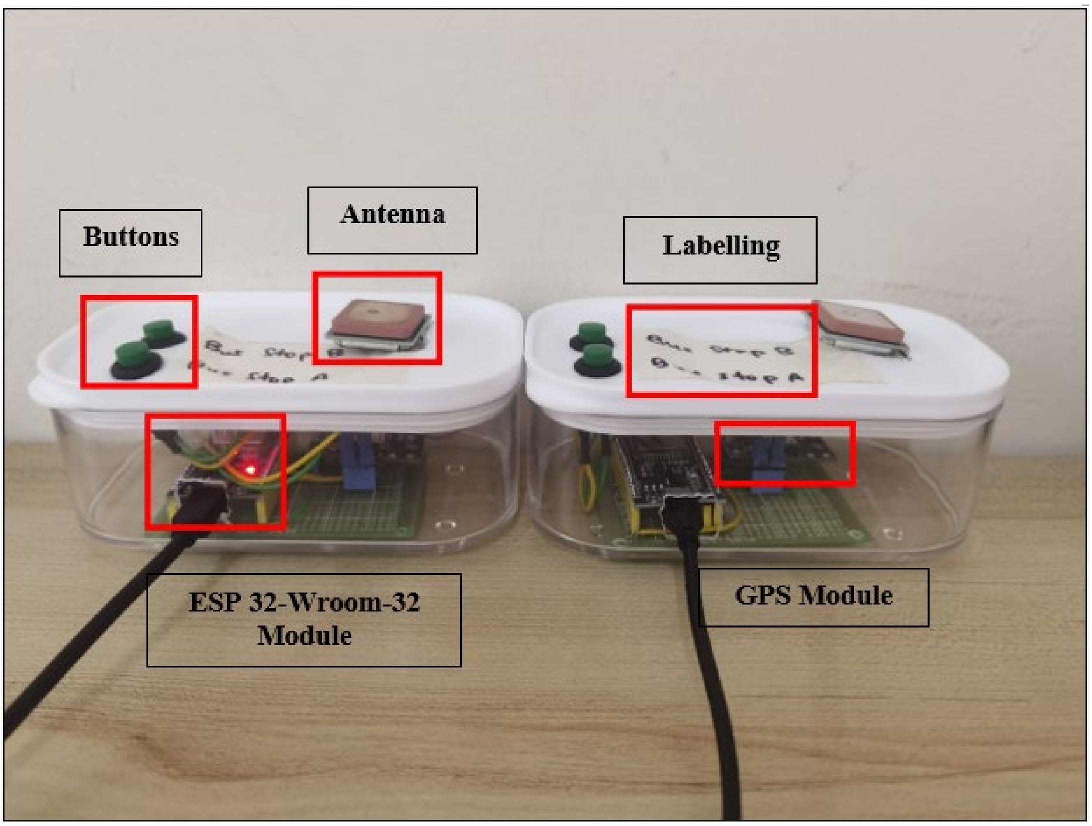

Fig. 5 *Prototypes connection with GPS Module on a donut board that placed inside the bus*

3. Results and Discussion

Table 1 shows the results of using the Analog Output pin of the LDR sensor. The 12-bit ADC is used to communicate with an LDR sensor and control the lighting related to the natural light in the environment. The LED will not be lit when the sensor has a range of values between 500 and 3,700, which corresponds to the day, and specifically to morning, afternoon, and evening. The LED lights up if the sensor reaches the maximum reading of 4095, which will happen during the night, rain, or cloud. This ensures that the LED is going to light properly under conditions of low illumination. The system effectively conserves energy by keeping the LED off during bright daylight and turning it on only in a dark environment or any other time when the natural light is not sufficient.

Table 1 *Testing using the AO (Analog Output) pin of the LDR sensor*

12-bit ADC of LDR sensor value approximate range	LED Condition	Time of Day/ Weather Condition
500 to 2000	OFF	Morning
2000 to 3000	OFF	Afternoon
3000 to 3700	OFF	Evening
4095	ON	Night
4095	ON	Raining
4095	ON	Cloudy

Table 2 shows the digital output (DO) pin of the LDR sensor with its output, LED light. During the morning, afternoon, and evening, the DO pin sends the LOW signals, indicating that there is enough natural light, and the LED remains turned off. In contrast, at night and during poor weather conditions such as raining or cloudy sky which represents a dark environment, the DO pin produces the HIGH signals, causing the LED to switch on to ensure proper illumination. This binary signal (LOW or HIGH) is directly related to the need of turning LED OFF or ON.

Table 2 *Testing using the DO (Digital Output) pin of the LDR sensor*

State	LED Condition	Time of Day/ Weather Condition
LOW	OFF	Morning
LOW	OFF	Afternoon
LOW	OFF	Evening
HIGH	ON	Night
HIGH	ON	Raining
HIGH	ON	Cloudy

The PIR sensor can effectively detect motion within a 7-meter range and a 110-degree angle, thus reliably detecting humans' motion. Table 3 shows results of the PIR sensor detecting some motion (state is HIGH), it will turn on the relay module, which in turn button switches on the fan. Such a setup allows the fan to run only as and when it is necessary, which improves energy efficiency and the comfort of the passengers. In the case that no motion is detected in four minutes, the fan automatically shuts off, which saves energy by not running unnecessarily. The integration of the PIR sensor with the relay module allows an energy-responsive and energy-efficient solution, thereby providing comfort in the bus shelter. Moreover, Table 3 is the testing results of a PIR sensor with a moving object. Table 3 can conclude that the PIR sensor is able to sense motion within 7 meters which is suitable to be used for smart bus shelter.

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Table 3 *Testing PIR sensor with moving object*

Distance between object and PIR sensor (meter)	State of PIR	Fan
0 until 1	HIGH	ON
1 until 2	HIGH	ON
2 until 3	HIGH	ON
3 until 4	HIGH	ON
4 until 5	HIGH	ON
5 until 6	HIGH	ON
6 until 7	HIGH	ON
7 until 8	LOW	OFF

Figure 6 shows the dashboard view of the Arduino Cloud when connected to two different prototype systems that are placed inside different buses. the Arduino Cloud dashboard, which displays real-time bus location with labelling of specific bus, a messenger informing the students when the bus approaches at which bus stop or destination, and real-time bus speed information. The Arduino Cloud administrator can adjust the scale of the Real-time GPS location information for different locations, enabling students to clearly see the bus location. Aside from that, the sticky note that showing the final destination, together with the real-time bus location in the dashboard, can improve the student user experience by allowing students to see which buses are heading to which locations rather than searching the information from an A4 paper displayed in front of the bus. Furthermore, the bus driver is able to manually press the button switches to send the specific message to the Arduino Cloud. After the button switches are pressed, the dashboard of the Arduino Cloud is able to display the messenger sent by pressing the button to inform the bus is approaching the respected bus shelter. Aside from that, the dashboard displays real-time speed data for the bus, helping students to know the bus moving status and condition. In this project, there are only two button switches to be tested to send the message, and the button switches can be varied by depending on how many bus shelters need to be tested in future projects.

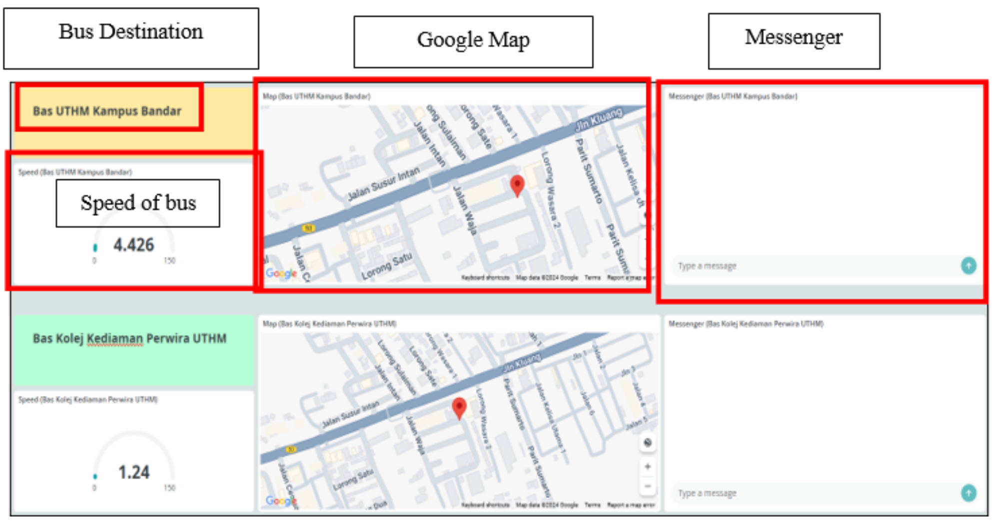

Fig. 6 *Dashboard of Arduino Cloud*

Figure 7(a) shows a Google Map view of the bus's real-time location. The red point on the map represents the real-time bus location, indicating that the bus is approaching bus stop A. This Google Map view allows passengers or students to view the real-time location of the bus, which improves their bus transportation experience. Figure 7(b) shows the dashboard messenger when the prototype's button A is pressed. When button A is pressed, a message ("The bus is approaching at bus stop A") is sent to Arduino Cloud and displayed on the dashboard. Besides that, Figure 8 shows the messenger's ability to display the correct message when button B is pressed, indicating that the bus is approaching bus stop B. The system's functionality enables passengers and students waiting at a certain bus stop to get ready to board the bus.

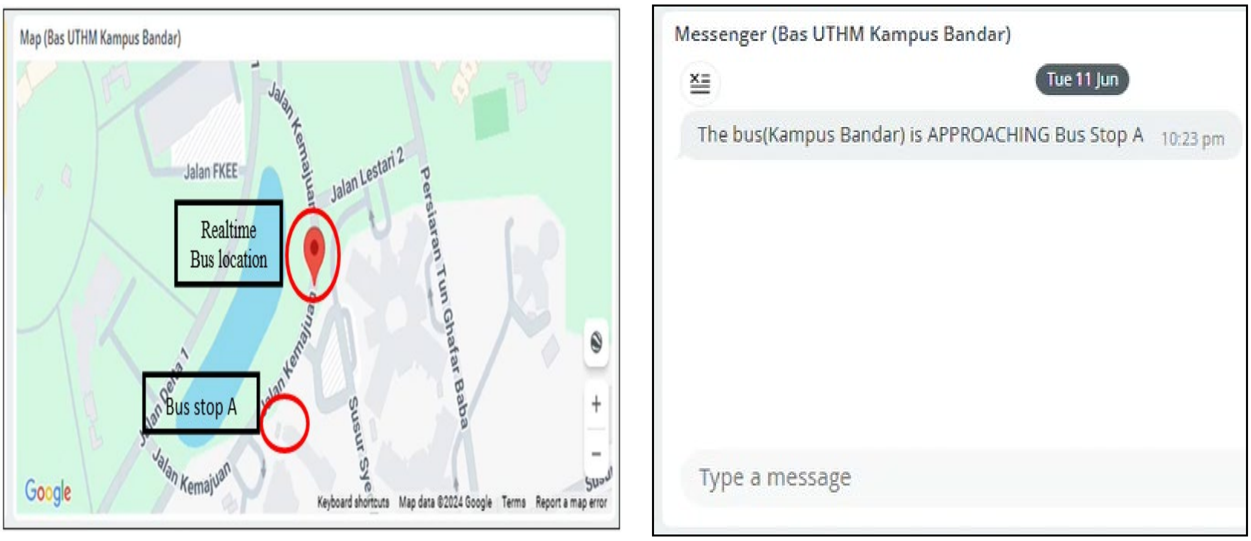

Fig. 7 *Dashboard view of Arduino Cloud (a) Real-time map view of real-time location of the bus p; (b) Messenger display when button A is pressed*

Fig. 8 *Dashboard display bus (UTHM Kampus Bandar) is approaching at Bus Stop B*

Figure 9 shows the mobile view of the dashboard for the IoT remote app. The mobile view can be obtained when the users install the IoT remote that is available at App Store, Google Play Store and Huawei App Gallery. It displays information in the same way that the Arduino Cloud window view does. To explain further, the administrator of the Arduino Cloud can modify the yellow or green sticky note to group the information delivered via a particular bus. The second row of the dashboard displays the bus's real-time location, followed by the third row, which displays the bus's speed. The last row of the dashboard represents the messenger that the bus driver can send after pressing specific button switches to notify them to get ready to board the bus. Based on the real-time information displayed, the system could help passengers or students in reducing the probability of missed buses and providing a smoother and more effective boarding experience.

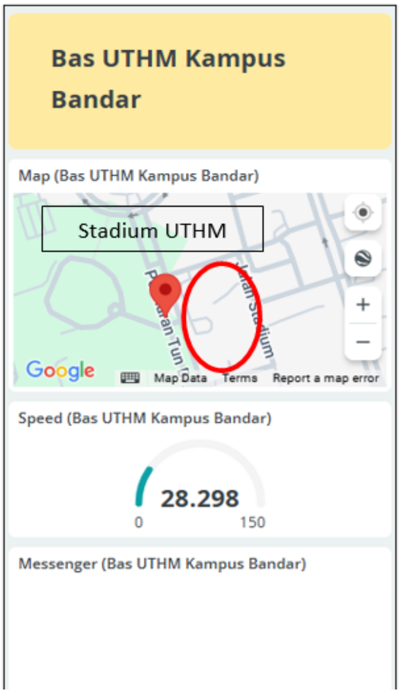

Fig. 9 *Mobile view of the dashboard of the IoT remote app*

4. Conclusion

As a conclusion, this project aims to implement smart solar-powered bus shelters on the UTHM campus and deals with several critical issues that students face. The implementation goes a long way in not only guaranteeing safety and convenience for passengers through the installation of real-time bus location displays, LED lighting, and fans but also harnessing solar energy as a clean and environmentally friendly source of power. Use of IoT technology within the smart bus shelters to provide accurate information on bus locations really reduces waiting time and increases passenger comfort. The real-time notification of the bus approaching that particular bus shelter also reduces the chances of missed buses and provides a smoother and more effective boarding experience.

This project is much more than improving the functionality of bus shelters; it contributes significantly to sustainable development. This project reduces the dependency on regular energy and extends the use of renewable energy, reducing the carbon footprint and supporting green initiatives. Extensive tests and thorough evaluations have proved the prototype's performance and reliability against different weather conditions and fan's load usage. This proves the conversion of traditional bus shelters into smart, energy-efficient systems, which is not just feasible but also very practicable for broader application.

In a nutshell, the solar-powered smart bus shelter project shows a clear vision of how technology can be used to enhance public transportation infrastructure. It has been proven that the use of smart technology integrated with renewable energy provides an effective and sustainable solution for the new challenges of urbanization. The successful implementation of this project can be replicated for urban areas to develop a more environmentally friendly and efficient transportation system, thereby creating a smarter and more sustainable urban environment.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.

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