IOT-based Mobile Solar Power Monitoring Station

(Stesen pemantauan Solar Mudah Alih Berasaskan IOT)

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Abstract

In this paper, a low-cost mobile-based multi-functional monitoring station is proposed to provide solar electricity and monitor weather and air quality. The main components of the monitoring station were developed with the Arduino Mega 2560, MQ135 gas sensor, and a PV solar panel. On the other hand, the software was developed in C using the Arduino IDE. The monitoring station works by collecting data on voltage, harmful gasses, and temperature of the surrounding. Test results in three locations in Kota Kinabalu have shown that the voltage, temperature, and air quality ppm varied from 11 – 13 V, 27.31 – 28.13 ^{0}C, and 70 – 83 ppm respectively, which is expected of the locality. These results are consistent with other designs and demonstrated that the device can reliably relay temperature and air quality data while providing solar power. Data collected by the monitoring station can be accessed remotely via the Blynk cloud server. Being mobile and self-powered, this device can be placed at any location for long-term monitoring.

Keywords: Solar power, weather, air quality, internet of things

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INTRODUCTION

POTENTIAL OF SOLAR ENERGY AND REMOTE AIR QUALITY MONITORING IN SABAH

The burning of fossil fuel accounts for the majority of the energy production capacity in Malaysia. Although the energy demands of Malaysia are generally met, the burning of fossil fuel leads to environmental degradation and climate change (Mekhilef et al., 2012). Currently, only 8% of Malaysia's energy is generated from renewable energy sources (Vaka et al., 2020). In the case of Sabah, it has been recently reported that electrification coverage is at 89.65 % and 67.05 % for urban and rural areas respectively (Borhanazad et al., 2013). Supplying electricity to the remote communities in East Malaysia is technically challenging and costly due to the geographical landscape of these two states. In contrast, the electrification level of Peninsular Malaysia is nearly 100% for both urban and rural areas. For this reason, solar energy is an attractive alternative for rural power supply in East Malaysia, as electricity can be generated locally without the need of constructing costly grids across difficult terrains.

In Kota Kinabalu, the annual solar radiation is reported at 182 W/m2 (Sukarno et al., 2015), or 15.87 MJ/m2/day (Markos & Sentian, 2016) which is comparable to other states in Malaysia (Mekhilef et al., 2012), (Mohammad et al., 2020). The high amount of available solar radiation in this region presents a good potential for electricity generation, especially in the sparsely populated rural areas. In a feasibility study of renewable energy in Borneo (Lau & Tan, 2020), it has been reported that solar power has a potentially lower cost compared diesel generators.

Following independence, Malaysia has adopted various policies towards achieving industrialization. The economic growth associated with industrialization, however, comes at a cost in terms of pollution and environmental degradation. Among the environmental issues, air pollution is a major issue, which is responsible for affecting human health. Air pollution consists of suspended liquid and solid particles, comprising mainly of particulate matter (PM), and several gases such as volatile organic compounds (VOCs), ozone (O3), carbon monoxide (CO), and nitrogen oxides (NO2) (Usmani et al., 2020). During the recurring haze occurrence, the particle matter (PM) has been identified as the main pollutant and results in the rise of hospital admissions due to raspatory issues (Latif et al., 2018). In Malaysia, there are 52 automatic and 14 manual air quality monitoring stations distributed across the country (Department of Environment, 2013). In response to the pollution of Sungai Kim Kim in 2019, 25 photoionization detectors (PIDs) have been installed in Pasir Gudang (Devei, 2020).

ENABLING TECHNOLOGIES AND RECENT DEVELOPMENTS

In recent years, the development of internet-of-things (IoT) technology has accelerated the growth of low-cost monitoring prices of solar energy photovoltaic (PV) and air quality. In large cities, solar and air quality monitoring are typically fixed-site systems dotted with a network of monitoring stations. However, the relatively high cost of installation and maintenance of these monitoring stations results in relatively sparse monitoring. As a result, accurate data can be provided but only at a few localities. Hence, low-cost Internet-of-things (IoT) based monitoring solutions can be beneficial to complement the current monitoring network. Although the performance of low-cost systems may vary from manufactures (Castell et al., 2017), numerous studies have reported that the sensor/monitoring performance is generally satisfactory (Morawska et al., 2018) when used within the conditions of the intended use. Therefore, these low-cost systems are well suited for rural areas where the available infrastructures cannot support commercial monitoring systems.

The Arduino, a low-cost open-source microcomputer is a key enabling component to a simple, user-friendly IoT system. It is widely used in control and monitoring. With an internet connection, various cloud networks can be easily configured to store the data acquired by the Arduino via applications such as Blynk and Energy Tracker app (Shanthi et al., 2018). The robustness of the Arduino has been demonstrated in (Lopez-Vargas et al., 2019), where it reliably performed real-time solar power monitoring under harsh environments over a 12-month test period. In (Jumaat & Othman, 2018), it was used to measure solar energy light intensity, voltage, and current and temperature using multiple sensors. In their tests, the highest voltage value reported was14.75 V at time 11.00 am, with a light intensity of 954 lux at a temperature of 34.32 ℃. The performance of the Arduino solar energy station can be further improved by manual (Aigboviosa et al., 2018) and automatic (Morón et al., 2017) tracking. The Arduino microcontroller is also well suited for air quality monitoring.

Various works on low-cost "citizen scientists" have been implemented with satisfactory results. In (Fjukstad et al., 2018), the Sharp GP2Y1010AUOF optical dust sensor ($5.99) and DHT11 temperature and humidity sensor ($1.00) were used to design a mobile sensor kit. The MQ135 (CO2), MQ2 (LPG, Hydrogen, i-butane, propane, alcohol, smoke, and methane) and MQ-7 (CO) gas sensors can be used to detect various gasses (Kaur et al., 2016). The data collected from these sensors can be monitored remotely from cloud services (Kumar & Jasuja, 2017) or even Android apps (Husain et al., 2016).

RESEARCH OBJECTIVES

In this research, we propose a device with combined functions of solar energy generation and air quality monitoring. The device is designed to be mobile and self-sustainable. Remote monitoring can be accessed via the device's IoT function. The remote mobile solar monitoring station is thus capable of providing electricity and report data on voltage, temperature, and air quality. (Pal et al., 2017)

MAIN EQUIPMENT AND MATERIAL

SOLAR PANEL

Photovoltaic Module SPM010-M is the name of a solar panel designed by Solar Power Mart. The efficiency is the solar have a low voltage- temperature coefficient ensures high-temperature operation. It is capable of producing power of 10 W, at 18 V 0.56 A. It also up to 17.00% solar cell and up to 9.85% module efficiency.

USB POWER SOLAR CHARGE CONTROLLER

The charge controller's function is to provide stable charging for the 12 V battery. It is connected between the solar panel and the battery. The controller will recognize the system rated voltage when started up. If the battery voltage is lower than 18V, it will recognize the system as 12V. If the battery voltage is greater than 18V, it will recognize the system as 24V.

ARDUINO MEGA 2560

The Arduino Mega is a microcontroller board based on the ATmega2560 as shown in Figure 3.10. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

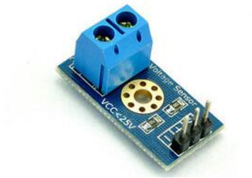
(a) PV solar panel

(b) USB power solar charge controller

(c) Arduino mega 2560

(d)DS18B20 digital temperature sensor

(e) ASC712 current sensor



(f) 5 V voltage sensor

(g) MQ135 air quality sensor

(h) ESP8266 wi-fi module

Figure 1. List of main equipment and material

DS18B20 DIGITAL TEMPERATURE SENSOR

The sensor is used to measure the temperature of the locality. It was selected for its waterproof feature, and compatibility with Arduino voltage of 3.0 to 5.5 V. The DS18B20 provides 9 to 12-bit (configurable) temperature readings over a 1-Wire interface so that only one wire (and ground) needs to be connected from a central microprocessor.

ASC712 CURRENT SENSOR

The current sensor is used to measure the incoming charging current to the solar charge controller. It is a 5 V compatible Hall transducer which converts the measured current to voltage.

5V VOLTAGE SENSOR

The voltage sensor is a device that converts voltage measured between two points of an electrical circuit into a physical signal proportional to the voltage. Connections positive and negative are electrical conserving ports through which the sensor is connected to the circuit.

MQ135 AIR QUALITY SENSOR

The air quality sensor is used for detecting a wide range of gases, including NH3, NOx, alcohol, benzene, smoke and CO2.

ESP8266 WI-FI MODULE

The Wi-Fi module is used for internet connection. The internet enables Arduino IoT communication that provides real-time remote data acquisition and monitoring.

OTHER MISCELLANEOUS COMPONENTS

In addition to the main items stated here, the design was complemented with a 12 V lead battery, LCD screen, and discreet electronic components. The casing of the monitoring station was constructed mainly with wood, with caster wheels attached to the bottom. The Blynk application was used to develop the user interface for the online monitoring process. Figure 1 shows the main components used.

CIRCUIT CONSTRUCTION AND PROGRAMMING

TEMPERATURE SENSOR WIRING

The Temperature Sensor to LCD connection is using pin 7, 6, 5, 4, 3, 2 on Arduino to send the data communication. Connect the Ground and 5V pin to the breadboard. Then, for the temperature sensor put the resistor on the Data and VCC pin and connect the data pin to pin 8 on Arduino. Then, directly connect the ground pin on the breadboard. The connection of the temperature sensor to the Arduino microcontroller is shown in Figure 2.

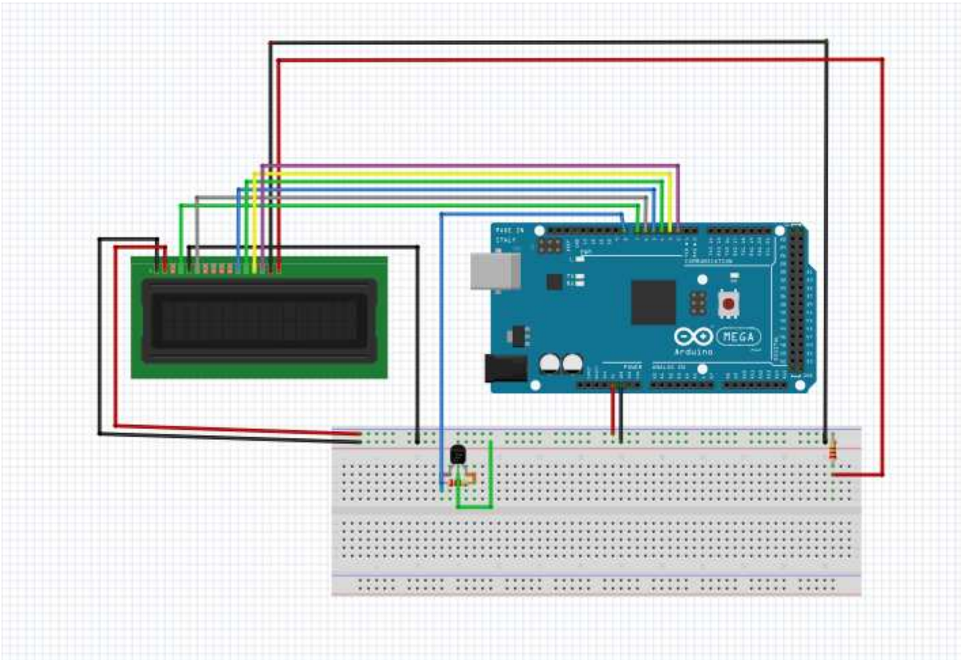


Figure 2. Circuit for temperature sensor to LCD and Arduino

VOLTAGE SENSOR TO LCD AND ARDUINO

The Voltage Sensor to LCD connection is using pin 7, 6, 5, 4, 3, 2 on Arduino to send the data communication. Connect the Ground and 5V pin to the breadboard. Then, for the voltage sensor connect the Ground and Sense pin to the A2 pin on Arduino. Then, directly connect the ground pin on the breadboard. The circuit diagram of the voltage sensor can be found in Figure 3.

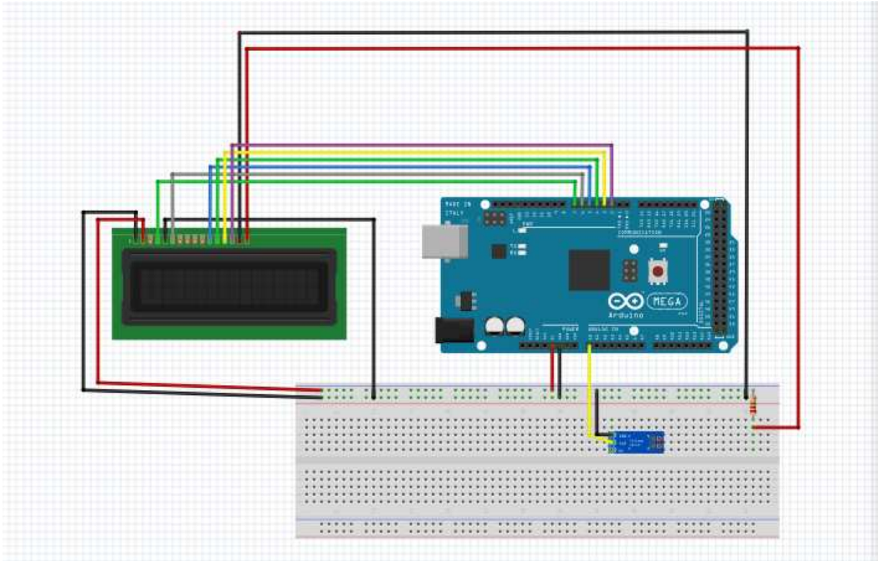


Figure 3. Circuit for voltage sensor to LCD

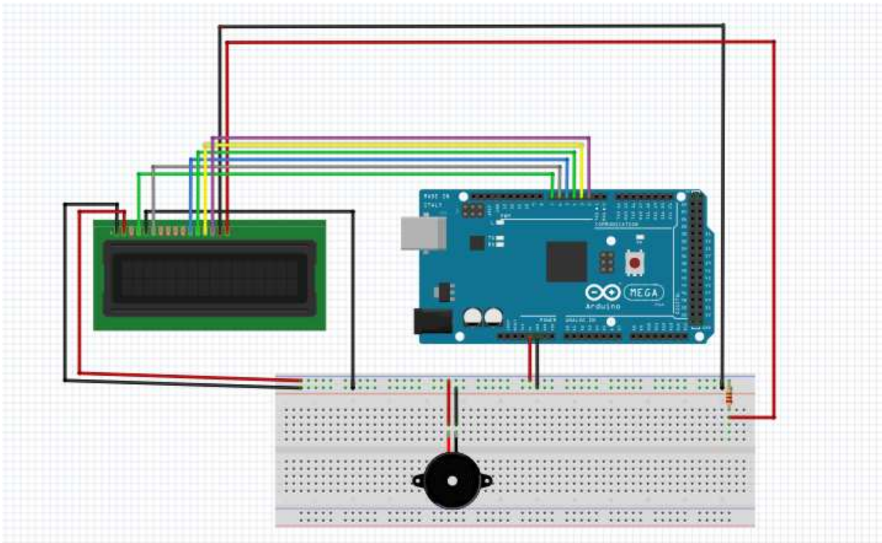


Figure 4. Circuit for buzzer and percentage to LCD and Arduino

<u>BUZZER AND PERCENTAGE TO LCD AND ARDUINO</u>

The buzzer to Arduino connection is using Ground and 5V pin to breadboard, as shown in Figure 4. Then, the buzzer will buzz when the battery percentage low than 100.

<u>MQ135 AIR QUALITY SENSOR TO LCD AND ARDUINO</u>

The MQ135 Air Quality Sensor to LCD connection is using pin 7, 6, 5, 4, 3, 2 on Arduino to send the data communication. Figure 5 shows the connection of the air quality sensor to the Arduino. Connect the Ground and 5V pin to the breadboard. Then, for the MQ135 Air Quality Sensor connect Digital Out A0 pin on Arduino. Then, directly connect the Ground and VCC pin on the breadboard. For the LED Red and Green connection, the short leg connects to the ground on the breadboard. Then, for the long leg on Red LED connected to pin 11 and for the Green LED connects to pin 10.

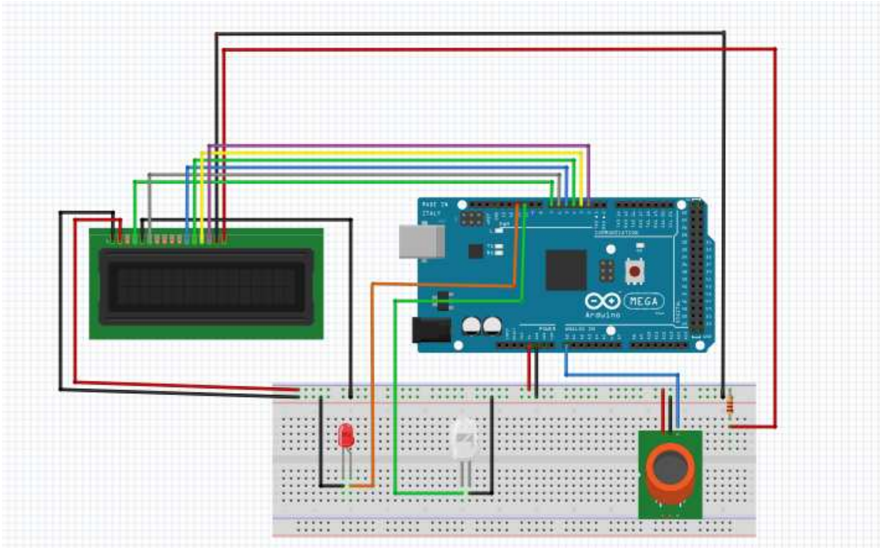


Figure 5. MQ135 Air quality sensor to LCD and Arduino

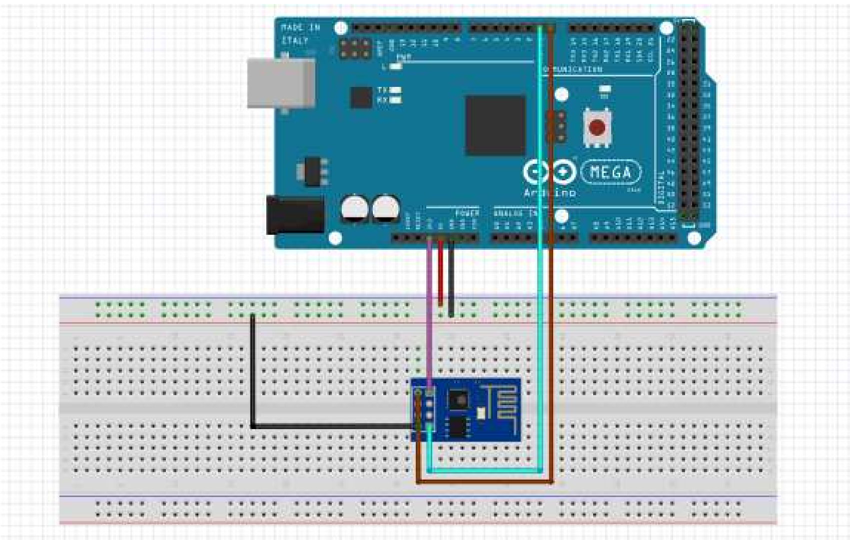


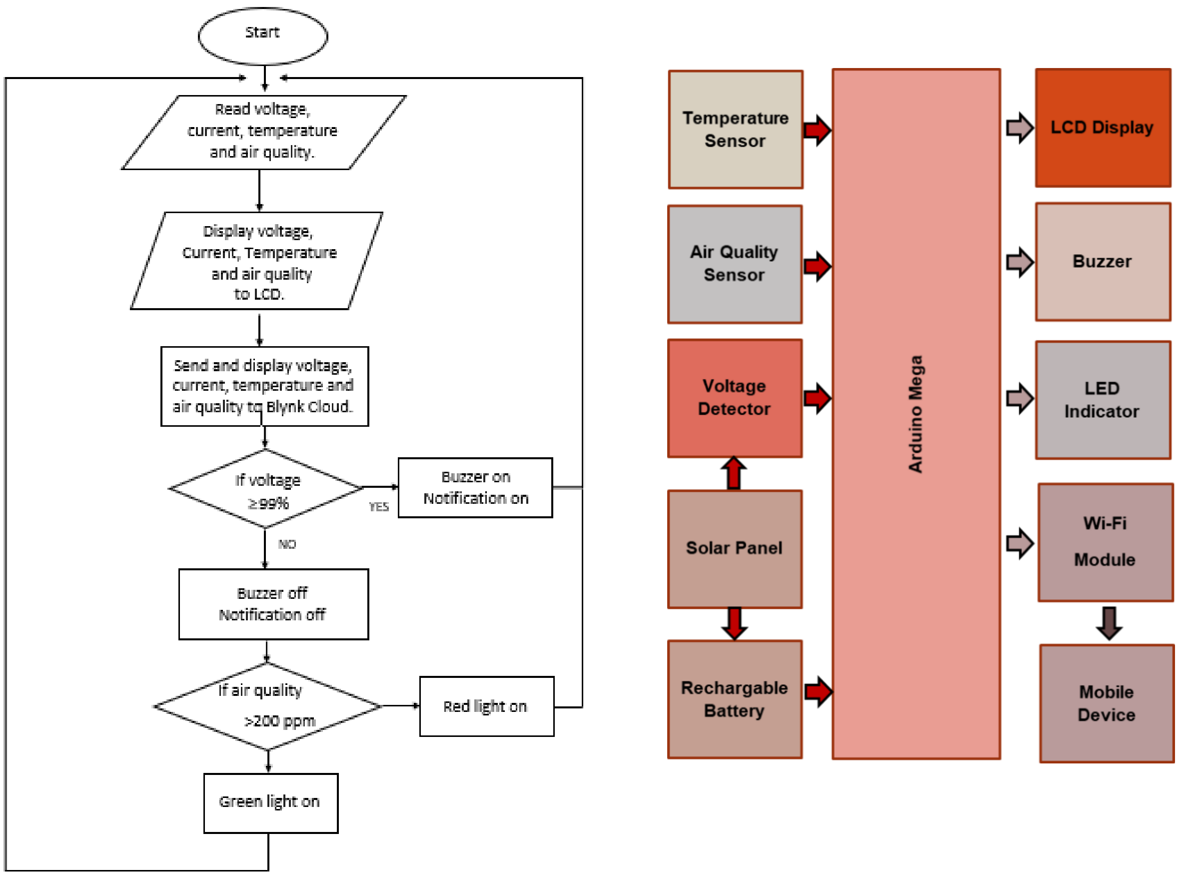
Figure 6. Wi-Fi module to Arduino

<u>WI-FI MODULE TO ARDUINO</u>

The Wi-Fi Module to Arduino connection connects the Ground pin to the breadboard and the input pin on 3.3V. For the TX connect to TR pin and for the TR connect to TX pin. Then, the Wi-Fi module will connect with the mobile and send all the data on the Blynk Cloud Application. The connection of the Wi-Fi module to the Arduino is shown in Figure 6.

SOFTWARE DESIGN

The software was developed following the hardware design. The input devices consisted of the temperature sensor, air quality sensor, and voltage detector. The solar panel is not directly connected to the Arduino. It is connected to the voltage detector and the rechargeable battery. The input voltage data is acquired through the voltage detector sensor. On the interface front, the LCD provides status information and the buzzer and LEDs provide alarm feedback. The Wi-Fi module provides communication means with remote devices which is accessible via the Blynk application.



(a) (b)

Figure 7. The software algorithm was designed around the hardware. Shown here are: (a) the flow chart and (b) the hardware block diagram.

The main program was designed to acquire the voltage, current, temperature, and air quality data. The flow chart of the program is shown in Figure 7 (a). These data are sent to the LCD screen for display purposes. At the same time, these data are sent to the Blynk Cloud server via an internet connection. The closed-loop portion senses the voltage, if the battery charge level is above 99%, then the buzzer and notification turn on. Otherwise, the buzzer and notification remain off and the sense loop for the air quality commences. If the air quality sensor detects a level of above 200 ppm, the red LED on the display panel will turn on. Otherwise, the green LED (on by default) remains on, and the program loops back to the starting point.

The software for the mobile monitoring station was developed in C language in the Arduino IDE developer. Excerpts of the program are shown in Figure 8 (a) and Figure 8 (b) respectively. To use the voltage sensor, the I2C / TWI device is enabled by including the Wire.h library. The LiquidCrystal.h library simplifies the programming communication to the LCD screen. The voltage is analog and acquired with the analogRead instruction. The voltage is defined as:

$$Voltage = \left(\frac{adc\ value}{resolution}\right) \times Vcc \quad (1)$$

The ADC resolution of the Arduino Uno is 1024. The supply voltage is 5 V. Therefore the actual voltage as acquired by the voltage sensor can be calculated by using the relationship defined in (1). The program for the Wi-Fi module utilizes the ESP8266 library, which is essential for programming interface with the Arduino.

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(a) Program for Voltage Sensor to LCD And Arduino

```
#include <Wire.h>
#include <LiquidCrystal.h>
LiquidCrystal lcd(7, 6, 5, 4, 3, 2);

void setup()
{
  pinMode(A2, INPUT);
  Serial.begin(9600);
  delay(1000);
  sensor.begin();
  lcd.begin(16, 2);
}
void loop()
{
  adcvalue = analogRead(analogchannel);
  Voltage = (adcvalue / 1024.0) * 5000;
  ecurrent = ((Voltage - offsetvoltage) /
sensitivity);
}
{
          lcd.setCursor(0, 0);
          lcd.print("    VOLTAGE     ");
          lcd.setCursor(0, 1);
          lcd.print("     ");
          lcd.print(voltage);
          lcd.print("V     ");
}
```

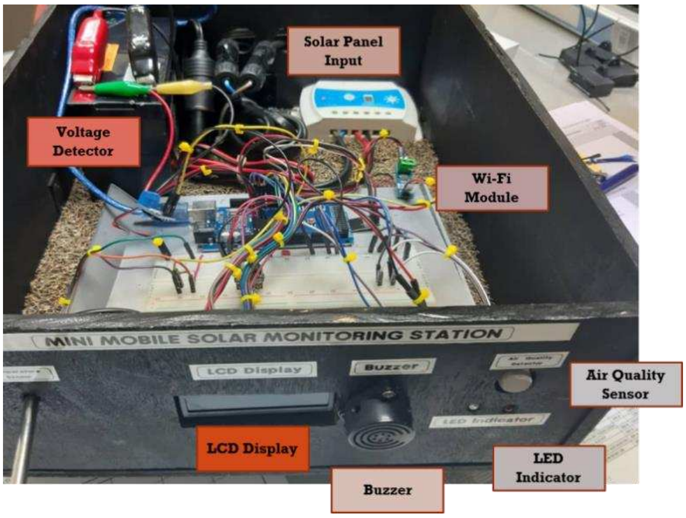
(b) Program for Wi-Fi Module

```
#include <ESP8266_Lib.h>
#include <BlynkSimpleShieldEsp8266.h>
#include <SoftwareSerial.h>
#define ESP8266_BAUD 115200
#define BLYNK_PRINT Serial
#define BlynkSimpleEsp8266.h

SoftwareSerial EspSerial (0, 1);
ESP8266 wifi(&Serial);

char auth[] =
"2qPWHt3GEdNurPPieRhy5EqrODfInxTL";
char ssid[] = "juliesha";
char pass[] = "juliesha99";

BlynkTimer timer;
void setup()
{
  Serial.begin(ESP8266_BAUD);
  delay(10);
  Blynk.begin(auth, wifi, ssid, pass);
  timer.setInterval(1000L, myTimerEvent);
  timer.setInterval(1000L, SendTemp);
}
void myTimerEvent()
{
  voltage = analogRead(A2) / 40.92;
  Blynk.virtualWrite(V5, voltage);

  sensor.requestTemperatures();
  temperature = sensor.getTempCByIndex(0);
  Blynk.virtualWrite(V4, temperature );

  current = (analogRead(A1) + 512) / 20.48;
//max 25A
  Blynk.virtualWrite(V3, current );

  airquality = analogRead(A0);
  Blynk.virtualWrite(V2, airquality);
}
void loop()
{
  Blynk.run();
  timer.run();
}
```

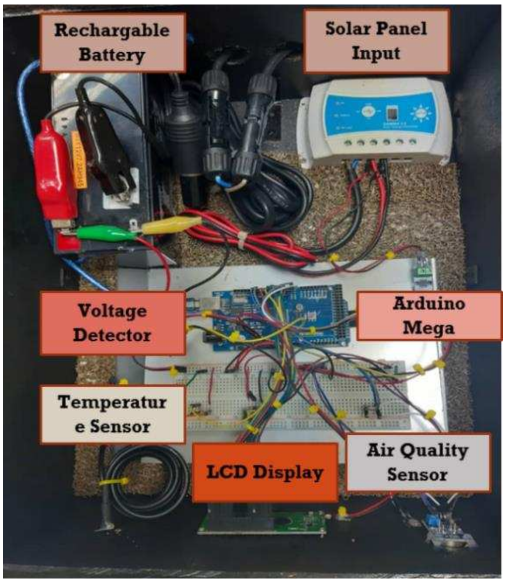
Figure 8. Selected program excerpts for (a) voltage sensor and (b) Wi-Fi module

PHYSICAL DESIGN

Shown in Figure 9 (a), the chassis of the project was constructed mainly of wood. Inside the chassis, the electronic components were secured with the necessary connectors and fasteners. A close-up of the component layout is shown in Figure 9 (b). The temperature sensor and voltage detectors are placed in the chassis while the air quality sensor is mounted to the wall of the chassis. In Figure 9 (c), the user interface consists of a power switch, the LCD display, buzzer and LED indicator. The air quality sensor can be found here also. Measuring 31 cm x 15 cm x 38 cm, the station is portable and can be deployed easily. For flexibility, the PV was mounted on the top of the chassis on a rocker. This allows the angle of the PV to be manually adjusted to the strongest solar radiation. The project was developed with a cost of RM 436. The detailed component list and the cost are shown in Appendix 1.

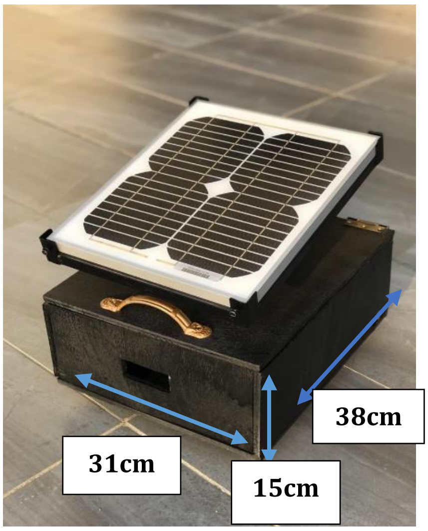


(a) Electronic components and wiring



(b) Close-up view of electronic components

(c) Completed front view of the monitoring station showing the user interface



(d) Dimensions of the monitoring station

Figure 9. Physical construction of the mini solar mobile monitoring station

TEST PROCEDURES AND RESULTS

To assess its function, the monitoring station system was placed outdoors for four hours from 1 pm to 5 pm. The reading of the voltage (V), temperature (0C), and air quality (ppm) from the corresponding sensors was logged in the Blynk cloud server. Three sites were chosen to conduct the test, which are Kota Kinabalu Industrial Park (KKIP), Nexus Karambunai, and Sabah Port. KKIP and Sabah Port are industrial areas while Nexus Karambunai is a resort. These three sites, located in the Teluk Sepanggar area are located approximately 10 Km from each other. The location map of test sites is presented in Figure 10.

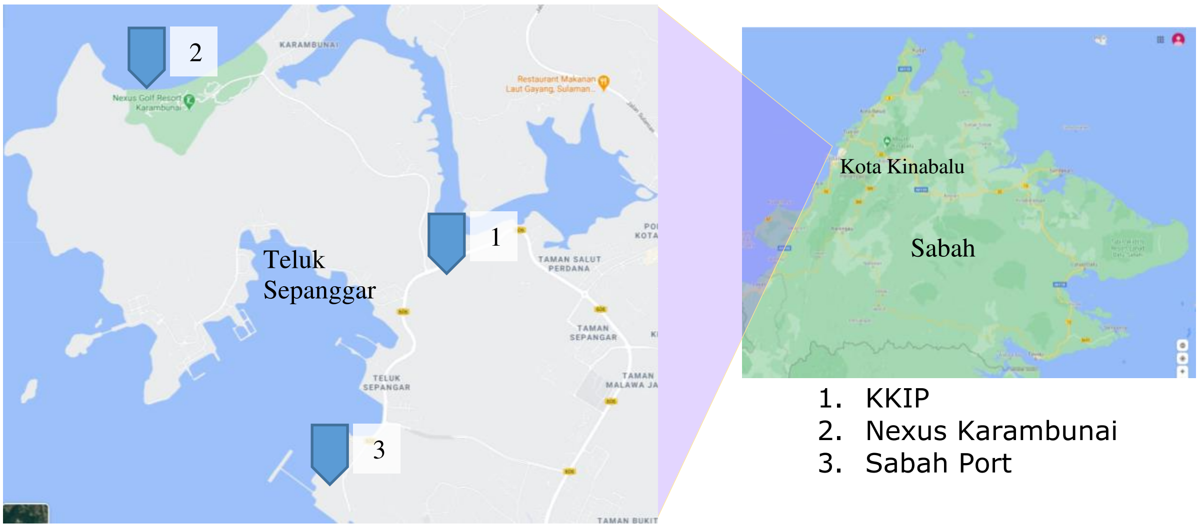


Figure 10. Location of the test site at KKIP, approximately 30 Km north of Kota Kinabalu

Table 1 shows the results of the function test. For all three locations, the charge voltage of the battery increased from 10 V to 13 V over four hours, which is similar to the trend as reported in (Jumaat & Othman, 2018). As a result, the monitoring station can be completely self-powered. The air quality reading from the gas sensor shows a similar reading to (Kaur et al., 2016). This shows that the PV cell provided enough power to fully charge the battery. The temperature sensor registered temperatures which varies throughout the day depending on the weather. In Table 2, the data shows the charging voltage of a fully discharged battery over 12 hours from sunrise to sunset. The highest increment occurred between 8.00 a.m. to 2.00 p.m. In comparison, the trends of the output are similar to (Aigboviosa et al., 2018).

Table 1. Monitoring data reading testing

Venue	**Time**	**Voltage (V)**	**Temperature (Celsius)**	**Air quality (ppm)**
KKIP	1:00 P.M	10.93	27.31	74
(08 oct 2019)	3:00 P.M	12.3	27.44	72
	5:00 P.M	12.93	27.56	70
Nexus Karambunai	1:00 P.M	10.73	27.31	74
(04 oct 2019)	3:00 P.M	11.88	27.44	72
	5:00 P.M	12.73	27.56	70
Sabah Port	1:00 P.M	10.05	28.06	83
(01 oct 2019)	3:00 P.M	11.08	28.07	80
	5:00 P.M	12.5	28.13	81

CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

We have presented an IoT enabled multi-functional mobile solar-powered monitoring station which can provide voltage, temperature, and air quality information. This mobile station is self-powered and is also capable of delivering power. The output of sensors has been compared and verified with similar works, which shows that the readings are consistent with other maker home-developed systems. The availability and support of the Arduino and its compatible devices allowed us to develop the monitoring station at a minimal cost of RM 436.

For full commercial applications, we recommend the following works: first, the real output power can be acquired by interfacing a current sensor. Next, although the data is available on the Blynk server, we suggest the development of a software interface that allows direct data download from the Arduino to a computer. Finally, the weather monitoring capability can be further upgraded with wind speed and dust sensors.

Table 2. Battery Charging Data Testing

Time	Temperature	Voltage
6:00 A.M	24	0V
8:00 A.M	25	0.22V
10:00 A.M	26	1.30V
12:00 P.M	26	2.56V
2:00 P.M	27	3.89V
4:00 P.M	26	4.60V
6:00 P.M	25	5.90V

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APPENDIX 1

Mobile solar monitoring station cost of material

COMPONENTS	QUANTITY	UNIT PRICE (RM)	AMOUNT (RM)
Wood	1	22.90	22.90
Solar panel	1	200.00	200.00
Charge controller	1	30.00	30.00
Arduino mega	1	42.40	42.40
Battery 12V	1	50.00	50.00
LCD (16x2)	1	11.00	11.00
Temperature sensor	1	7.50	7.50
Current sensor	1	15.00	15.00
Voltage sensor	1	3.00	3.00
Air quality sensor	1	6.70	6.70
Wi-fi module	1	14.50	1.50
Breadboard	1	9.00	9.00
Jumper wire	2	3.00	6.00
Potentiometer	1	3.00	3.00
LED (Red, green)	2	0.50	1.00
Buzzer	1	2.50	2.50
Crocodile clip	2	2.00	4.00
wheel	4	5.00	20.00
Resistor (1 kΩ)	2	0.50	1.00
		TOTAL	436.10