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Design and Build Voltage and Current Monitoring Parameters Device of Rechargeable Batteries in Real-Time Using the INA219 GY-219 Sensor

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Abstract

Research on the manufacture of devices for monitoring battery voltage and current parameters has been carried out and developed using different types of sensors. This research have been released a device that can monitor battery voltage and current parameters in real time in the charge and discharge process using one sensor. The device is made using a microcontroller in the form of an Arduino Mega XPro 2560 R3, with an input in the form of an INA219 GY-219 sensor to monitor battery voltage and current. The output of device is in the form of automatic control of the charge and discharge circuit through the LCD and relay to obtain data from monitoring the battery voltage and current parameters. The batteries used as materials to be tested in this study are rechargeable Li-ion types. The device can monitor the voltage and current parameters of the battery as it should and can work automatically according to the control program created and designed by the manufacturer. Based on the test results of the INA219 GY-219 sensor in reading the voltage, the average sensor accuracy level is 99.96%, the sensor error average rate is 0.034%, and the sensor precision average is 99.97%. Meanwhile, in the reading current, the average sensor accuracy level is 98.39%, the sensor error average rate is 1.608%, and the sensor precision average is 98.98%.

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Abstrak

Penelitian mengenai pembuatan perangkat untuk memonitoring parameter tegangan dan arus baterai telah banyak dilakukan dan dikembangkan dengan menggunakan jenis sensor yang berbeda-beda. Penelitian ini telah merealisasikan sebuah perangkat yang dapat digunakan untuk memonitoring parameter tegangan dan arus baterai secara real-time pada proses charge dan discharge dengan menggunakan satu sensor. Perangkat yang dibuat menggunakan mikrokontroler berupa Arduino Mega XPro 2560 R3, dengan input berupa sensor INA219 GY-219 untuk memonitoring tegangan dan arus baterai. Output perangkat yang dihasilkan berupa pengontrolan otomatisasi rangkaian charge dan discharge melalui LCD dan relay untuk mendapatkan data hasil monitoring parameter tegangan dan arus baterai. Baterai yang digunakan sebagai bahan untuk diuji pada penelitian ini berupa baterai rechargeable jenis Li-ion. Berdasarkan hasil pengujian sensor INA219 GY-219 dalam membaca tegangan diperoleh tingkat rata-rata akurasi sensor sebesar 99,96%, tingkat rata-rata error sensor sebesar 0,034%, dan tingkat rata-rata presisi sensor sebesar 99,97%. Sedangkan dalam membaca arus, diperoleh tingkat rata-rata akurasi sensor sebesar 98,39%, tingkat rata-rata error sensor sebesar 1,608%, dan tingkat rata-rata presisi sensor sebesar 98,98%. Perangkat yang dibuat dapat digunakan untuk memonitoring parameter tegangan dan arus baterai sebagaimana mestinya dan dapat bekerja secara otomatis sesuai dengan program pengdali yang dibuat serta rancangan pembuatan perangkat

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1. Introduction

Batteries are electrical energy storage devices essential in incredibly portable electronic devices. With the battery, the use of portable electronic devices can be more efficient because to activate, it does not have to be directly connected to a power source (Otong *et al.*, 2019). It is because, in the battery, electrochemical cells can convert chemical energy into electrical energy (Hadiyati *et al.*, 2018). The electrical energy produced by the battery is then used as a source of electrical energy to activate portable electronic devices.

Using electrical energy from batteries will increase with the development of existing electronic technology (Oetomo & Halim, 2017). Apart from being a source of electrical energy for portable electronic devices, batteries are also used to store electrical energy generated in power plants (Tumbelaka & Johannes, 2004). In its use, the battery must have a large and high energy capacity (Garcia-Valle & Lopes, 2013). Therefore, battery manufacturing research continues to improve battery performance (Thirunakaran *et al.*, 2013). Batteries with good performance are batteries that can store high energy, regenerate quickly, and have a long life (Rochman & Sembodo, 2014).

Battery performance can be determined by knowing the characteristics of charging and discharging the battery based on the values of the crucial parameters of the resulting battery (Prima *et al.*, 2013). In addition, by knowing the characteristics of the charge and discharge processes, the regeneration process of a battery can also be known (Munir *et al.*, 2015). To find out how the performance of a battery, various tests need to be carried out (Mulder *et al.*, 2013). Therefore, it is necessary to make a device to monitor battery parameters that can be used during the charge and discharge process.

The manufacture of battery parameter monitoring devices has been carried out by Syahadad and Zakri (2018). The device is an automatic battery charger to measure the estimated SOC of two Lead-Acid batteries by monitoring the battery voltage and current parameters. This device uses a voltage divider circuit, an ACS712 sensor, and Arduino Uno as the microcontroller. This device can work well but can only be applied for charging. Hidayat and Pradana (2018) made a monitor device for battery voltage and current parameters that can be used during the charge and discharge process. The device uses a voltage divider to monitor battery voltage, an ACS712-05B sensor, and a CLSA2CD sensor to monitor battery current. The device that is made can give good results but must use several sensors to get the results of monitoring battery voltage and current parameters.

Monitoring of voltage and battery parameters during the charge and discharge process has also been carried out by Soeprapto *et al.* (2019) by creating a Battery Management System (BMS) using a voltage divider circuit, ACS712-30A sensor, and LM35 IC. The BMS can work well in this study, but the ACS712-30A sensor provides monitoring results for current battery parameters with an average error value that is still relatively large. Handayani *et al.* (2020) made a monitoring system for voltage and current parameters using a single sensor in the form of the INA219 sensor, which was applied to an electrochemical cell with an electrolyte in the form of seawater. The sensor in the system can detect voltage and current with an accuracy of 99.73% and 95.85%, respectively.

Based on the results of several device manufacturers above, in this study, a real-time monitoring device for battery voltage and current parameters was created that can be used both in the charge and discharge processes. The components used in the device are the INA219 GY-219 sensor for monitoring battery voltage and current parameters, and the microcontroller used is Arduino Mega XPro 2560 R3. The device will also be equipped with a data logger system so that monitoring data can be recorded and stored automatically. Meanwhile, the battery is rechargeable, which is the material for monitoring the voltage and current parameters.

2. Research Methods

The tools used in this research consist of software and hardware. The software includes Fritzing 0.9.8, Arduino IDE 1.8.10, Eagle 9.6.1, SketchUp 2019, Origin Pro 2019, Microsoft Word 2019, and Microsoft Exel 2019. In comparison, the hardware used includes the SANWA CD800a multimeter, Heles UT-multimeter 883, PC/laptop, soldering iron, tin paste, drill, and other hardware.

The materials used in this research include Arduino Mega XPro 2560 R3, Arduino Mega sensor shield V2.0, INA219 GY-219 sensor, micro SD card, micro SD card adapter module, RTC DS3231 module, four-channel relay module, lime resistor 1 W 5.6 Ω, 1 W high power LED, 24 V 3 A switching power supply, XL4015 module, 10 kΩ multiturn potentiometer, digital volt & amp meter, 3.2 inch TFT LCD ILI9341, 3.2 inch Arduino TFT LCD Mega shield V2.2, 12 V DC fan, 5 V buzzer, BC547 transistor, 7805 regulator IC, 10 kΩ carbon resistor, female banana jack, 3D printing electronic box project, and 7.4 V 1100 mAh lithium-polymer (LiPo) battery.

2.1 Device Design

The design of a device for monitoring voltage and current parameters of rechargeable batteries in real-time using the INA219 GY-219 sensor as a whole is shown with a block diagram, as shown in **Figure 1**.

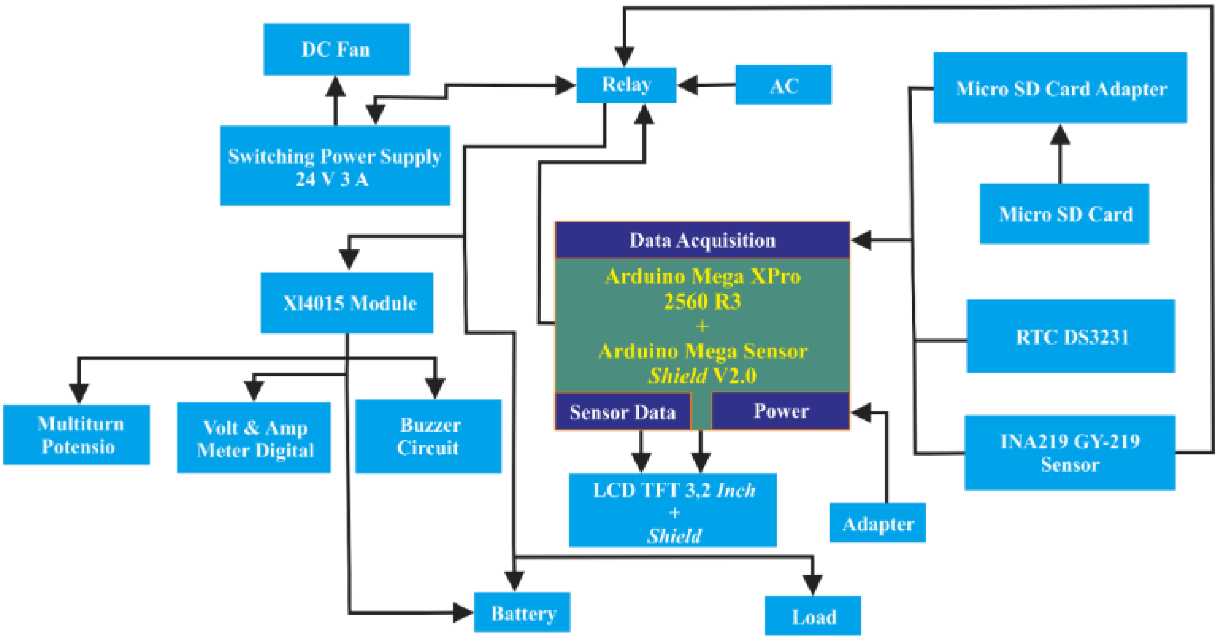


Figure 1. Device design block diagram

The device is designed to consist of 3 main parts, namely a series of charge, discharge, and data logger systems. The charge circuit that will be made uses the working principle of a variable power supply. The battery will be connected to the XL4015 module, which charges the battery with adjustable voltage and current according to charge needs through two 10 kΩ multiturn potentiometers. The multiturn potential is then connected to a digital volt & amp meter so that the voltage and current set to charge the battery can be known. The charge circuit is also connected to a buzzer circuit consisting of IC 7805, BC547 transistor, 10 kΩ carbon resistor, and a 5 V buzzer through the XL4015 module, which is used as an alarm when the battery that is charged using the XL4015 module enters the cut-off voltage phase during the charging process. It takes place to avoid overcharging the battery, which can damage the battery. Switching power supply 24 V 3 A is connected to an AC source to convert AC voltage to DC, which is helpful as an activator of the XL4015 module through a four-channel relay controlled by a microcontroller via a 3.2-inch TFT LCD so that the charge circuit can charge automatically.

While the discharge circuit consists of the INA219 GY-219 sensor, which is integrated with the battery and loaded via a four-channel relay using a microcontroller and a 3.2-inch TFT LCD, the INA219 GY-219 sensor helps monitor battery voltage and current parameters. The load used in the discharge circuit is two lime resistors 1 W 5.6 and high power LED 1 W arranged in series, which consume power on the battery. In its application, besides being used to monitor battery voltage and current parameters during the discharge process, the INA219 GY-219 sensor and load are also used to monitor battery voltage and current parameters during the charging process. The monitoring results will then be transmitted to the data logger system and displayed on the device via the microcontroller.

The data logger systems use a micro SD card adapter module equipped with a micro SD card and a DS3231 RTC module connected to a microcontroller. The micro SD card adapter and micro SD card modules in the data logger system function on the results of monitoring battery voltage and current parameters. In comparison, the RTC DS3231 module functions as a time source that provides information, including when the monitoring process occurs.

Overall, the device will be added with other components, such as a 12 V DC fan connected to a switching power supply that removes the hot air produced by the device when operating. In addition, the device will also use a 3.2-inch TFT LCD to display the results of monitoring battery voltage and current parameters.

2.2 Device box design

The box design of a device for monitoring voltage and current parameters of rechargeable batteries in real-time using the INA219 GY-219 sensor can be seen in **Figures 2 (a**) and **2 (b)**.

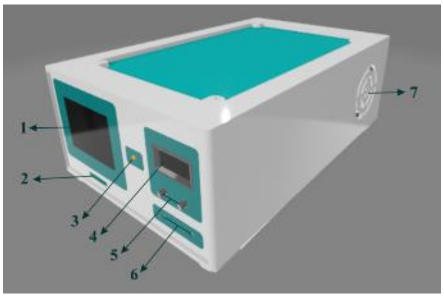


Figure 2 (a). The device box design looks corner front.

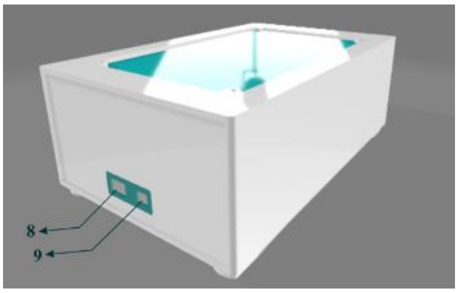


Figure 2 (b). The device box design looks corner behind.

Description:

1. LCD TFT 3,2 Inch;
2. Port micro SD card;
3. High power LED 1 W;
4. Digial volt & amp meter;
5. 10 kΩ multiturn potentiometer;
6. Battery input;
7. Exhaust fan hole;
8. Charge circuit port; and
9. Arduino port.

Figure 2 (a) and **Figure 2 (b)** show the box design for monitoring the voltage and current parameters of a rechargeable battery in real-time using the INA219 GY-219 sensor, which is visible from the front corner and seen from the back corner. The device box design display from the front corner depicts the device using several components, such as a TFT LCD micro SD card port as a slot to put a micro SD card into the device. In addition, there is a 1 W high power LED, digital volt & amp meter, multiturn potentiometer, positive (+) and negative (-) battery inputs, and an exhaust fan hole as a device hole in the side so that the DC fan is in the device box. It can release the hot air generated by the device when operating through these openings. In comparison, the device box design display from the back corner depicts the device using two ports: the charge circuit port, which connects the AC power source to the charge circuit, and the Arduino port to turn on the Arduino Mega XPro 2560 R3 as a device microcontroller.

2.3 Device Schematic

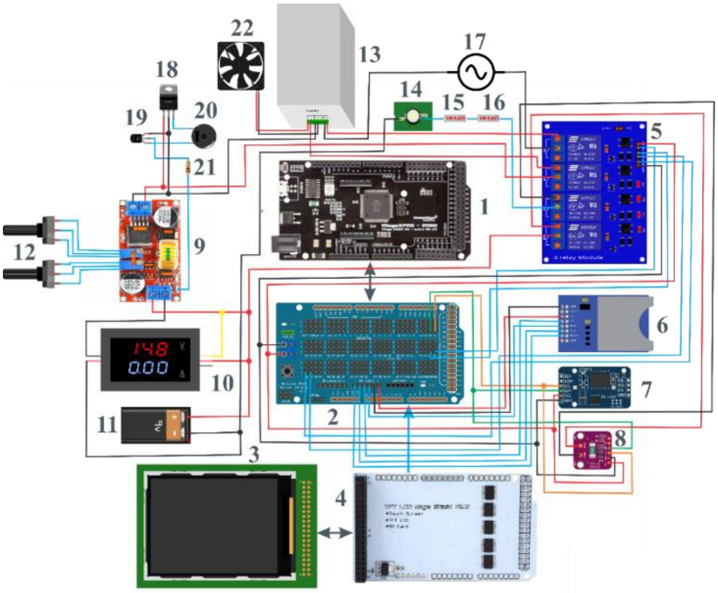


Figure 3. Schematic of the device circuit

description:

1. Arduino Mega XPro 2560 R3;
2. Arduino Mega sensor shield V2.0;
3. 3,2 inch LCD TFT ILI9341;
4. 3,2 inch Arduino LCD TFT Mega shield V2.2;
5. Four-channel relay module;
6. Micro SD card adapter module;
7. RTC DS3231 module;
8. INA219 GY-219 sensor;
9. XL4015 module;
10. Digital volt & amp meter;
11.
12. 10 kΩ multiturn potensiometer;
13. Switching power supply 24 V 3 A;
14. High power LED 1 W;
15. Lime resistor 1 W 5.6 Ω;
16. Lime resistor 1 W 5.6 Ω;
17. AC power source;
18. 7805 regulator IC;
19. BC547 transistor;
20. 5 V buzzer;
21. 10 kΩ carbon resistor; and

11. Battery; 22. 12 V DC fan;

A Schematic of a device for monitoring voltage and current parameters of rechargeable batteries in real-time using the INA219 GY-219 sensor is shown in **Figure 3**.

Figure 3 shows several components whose pins are connected or not connected to the Arduino pins. Ten digital Arduino Mega XPro 2560 R3 pins are used with two power pins. The 10 digital pins include pins D20, D21, D44, D45, D46, D47, D50, D51, D52, and D53. Pins D20 and D21 are the pins used for communication between the Arduino Mega XPro 2560 R3 and the I2C module found on the INA219 GY-219 sensor and RTC DS3231 module. Pins D44, D45, D46, and D47 function as input pins on the four-channel relay module, activating the device's charge and discharge circuits. Pins D50, D51, D52, and D53 are used for SPI communication between the Arduino Mega XPro 2560 R3 and the micro SD card adapter module. In comparison, the two power pins used are +5 V and GND pins. In addition, an Arduino Mega XPro 2560 R3 pin is also connected to the 3.2-inch Arduino TFT LCD Mega shield pin on the 3.2-inch TFT LCD ILI9341. There are 29 digital pins, namely pins D22–D46 and D50–D53, and two power pins, namely the +5 V and GND pins on the Arduino, used to activate the ILI9341 3.2 inch TFT LCD. Meanwhile, some components that are not connected to the Arduino Mega XPro 2560 R3 pin are the components that make up the charge circuit and load circuit.

2.4 Arduino Controller Program Design

Arduino Mega XPro 2560 R3 controller program is designed using Arduino IDE software. The program contains commands to perform the functions of the device controller circuit. The design of the control program is shown in the flowchart in **Figure 4**.

The flow chart shows the control program's design, which is made to carry out three main tasks. The first task is to perform automation commands using a four-channel relay module controlled via the main LCD menu display to activate the charge and discharge circuit. The second task of the controller program is to read the monitoring and measurement time data from the RTC DS3231 module, which is used when monitoring the battery voltage and current parameters, and convert it to a digital value. In comparison, the third task is storing monitoring data on the micro SD card in the micro SD card adapter module and displaying it on the LCD. The second and third tasks of the controller program are used to control the components of the data logger system builder.

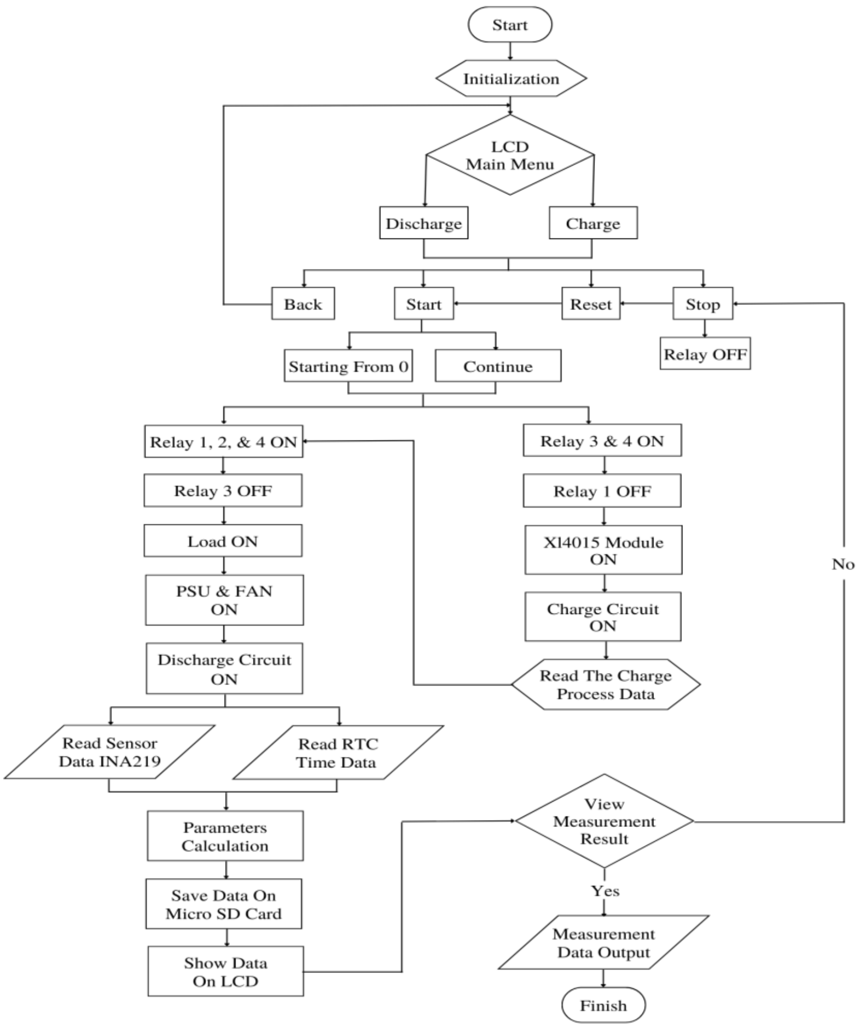


Figure 4. Flowchart of device controller program design

2.5 Device Component Test

This stage includes testing several components used in the device: the INA219 GY-219 sensor, RTC DS3231 module, micro SD card adapter module equipped with a micro SD card, 3.2 inch TFT LCD, and a four-channel relay module. Testing is done by connecting Arduino with test components, then running program commands in Arduino IDE. If some of these components run according to program commands, the device can already be used for data retrieval. In addition, to the module running correctly, the INA219 GY-219 sensor was also measured to determine the error, accuracy, and precision of the INA219 GY-219 sensor, which was used to collect data for monitoring battery voltage and current parameters.

Two parameters are tested on the INA219 GY-219 sensor, including voltage and current. The measurement data is used to calculate the error, accuracy, and precision of the INA219 GY-219 sensor in reading voltage and current using **Equations 1**–3.

$$\%\ error = \left|\frac{Y\text{-}X_n}{Y}\right| \times 100\% \qquad \textbf{(1)}$$

$$\%\ accuracy = \left(1\text{-}\left|\frac{Y\text{-}X_n}{Y}\right|\right) \times 100\% \qquad \textbf{(2)}$$

$$\%Precision = \left(1\text{-}\left|\frac{X_n\text{-}\overline{X_n}}{\overline{X_n}}\right|\right) \times 100\% \qquad \textbf{(3)}$$

with:
Y = Reference parameter value;
X_n = *n-th* measured parameter value; and
$\overline{X_n}$ = Average value of the measured n parameter.
(Jones dan Chin, 1991).

2.6 Device Test Design

Device testing is done by running all device components, software, and hardware and implementing the device to retrieve data monitoring battery voltage and current parameters in real time. The monitoring data for battery voltage and current parameters are obtained from the results of the INA219 GY-219 sensor readings contained in the device. There are two processes for monitoring battery voltage and current parameters: charge and discharge. The first data retrieval is carried out on the discharge process on the previously charged battery until it reaches its maximum state. The discharge process is carried out until the battery is empty. After the discharge process data retrieval, the next step is to collect data on the charging process using a constant voltage and current until the battery is fully charged. The battery voltage and current parameter data obtained from the monitoring results will then be stored on a micro SD card in txt format. In comparison, the battery used as a test material for monitoring the voltage and current parameters is a rechargeable battery of the Lithium-Ion (Li-Ion) type.

3. Results and Discussions

3.1 Device Design Realization

The device for monitoring the voltage and current parameters of rechargeable batteries in real-time using the INA219 GY-219 sensor has been realized with results as shown in **Figure 5**.

Figure 5. Realization of the battery voltage and current parameter monitoring device

Figure 5 shows the device's display that has been realized for monitoring a rechargeable battery's voltage and current parameters. The device consists of several components located in several parts, such as the inside, front, and back of the device, as shown in Figure 5 (a)–(c). The device box used is a 3D printing box that is printed using Polylactic Acid (PLA) material with a size of 34 cm × 21 cm × 12 cm with a thickness of 5 mm.

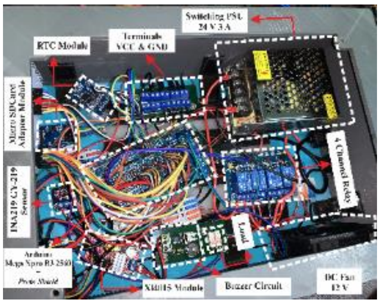


Figure 5 (a). Inside view of the device

Figure 5 (b). Behind the view of the device

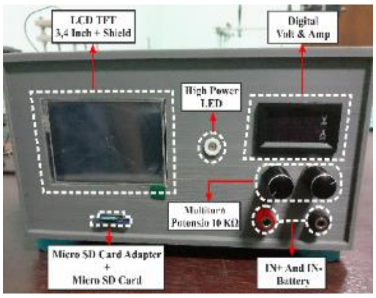


Figure 5 (c). Front view of the device

The inside of the device consists of several components such as Arduino Mega XPro 2560 R3, which is equipped with Arduino Mega sensor shield V2.0, INA219 GY-219 sensor, RTC DS3231 module, micro SD card adapter module equipped with micro SD card, charge circuit, discharge circuit, DC 12 V 0.15 A fan and buzzer circuit. The front of the device consists of a 3.4-inch TFT LCD equipped with a 3.2-inch Arduino TFT LCD, Mega shield V2.2, digital volt & amp meter, multiturn potentiometer, banana jack is used for positive (+) and harmful (-) battery input to the device, 1 W high power LED as a load connected in series with two lime resistors 1 W 5.6 Ω and as an indicator of the discharge process. In addition, a slot at the bottom of the LCD is used to place and remove a micro SD card from the device. The back of the device has two ports: the Arduino port and the charge circuit port.

3.2 INA219 GY-219 Sensor Testing

Testing the INA219 GY-219 sensor was carried out by comparing the sensor output results in the form of voltage and current with the voltage reading results using a SANWA CD800a multimeter and current readings using the Heles UX-883 multimeter before being implemented on the device.

3.3.1 Voltage Testing on the INA219 GY-219 Sensor

Testing the voltage of the INA219 GY-219 sensor is done by connecting the power supply and the SANWA CD800a multimeter to the Vin (+) and Vin (-) sensors. In comparison, the INA219 GY-219 sensor is connected to the Arduino Mega pin and PC/Laptop via the I2C sensor pin and the USB port. Then the result of the voltage read by the sensor will be adjusted to the voltage reading of the SANWA CD800a multimeter with the voltage source (Vref) coming from the power supply. The sensor voltage test was carried out for five repetitions of measurements, each containing 20 data. The data in the measurement includes a voltage variation of 1–10.5 V with an interval of 0.5 V for each measurement. The results of voltage testing on the INA219 GY-219 sensor against the SANWA CD800a multimeter are shown in **Figure 6**.

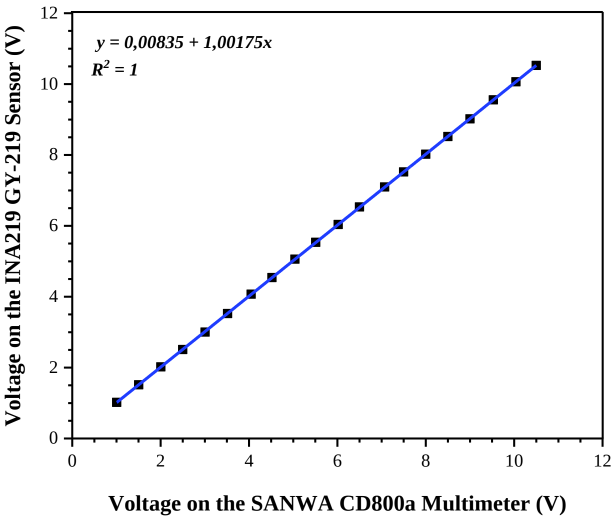


Figure 6. Graph of voltage testing on the INA219 GY-219 sensor against the SANWA CD800a multimeter

Figure 6 shows a graph of the voltage testing on the INA219 GY-219 sensor against the SANWA CD800a multimeter with the R^2 value obtained of 1 and the linearity equation or linear regression [y = 0.00835 + 1.00175x] so that the equation is obtained to get the voltage value as shown in **Equation 4**.

$$\textit{voltage calibration} = (\textit{load voltage} - 0.00835)/1.00175 \qquad \textbf{(4)}$$

Furthermore, the obtained equation is then entered into the device control program so that the voltage reading on the INA219 GY-219 sensor corresponds to the SANWA CD800a multimeter. The following is a program for controlling the battery voltage and current parameter monitoring device for reading the voltage value entered by the linearity equation.

```
float shuntvoltage = 0;
float busvoltage = 0;
float current_mA = 0;
float loadvoltage = 0;
float voltagecalibration = 0;

shuntvoltage = ina219.getShuntVoltage_mV();
busvoltage = ina219.getBusVoltage_V();
current_mA = ina219.getCurrent_mA();
loadvoltage = busvoltage + (shuntvoltage / 1000);
voltagecalibration = (loadvoltage-0.00835)/1.00175;
```

After the linearity equation is entered into the controller program, the re-test is carried out to ensure the error rate, accuracy, and voltage precision on the INA219 GY-219 sensor based on calculations. The results of testing the linearity equation of the sensor voltage are shown in **Table 1**.

The results of the re-test of the voltage on the INA219 GY-219 sensor are then compared with the results of the voltage measurements read on the SANWA CD800a multimeter so that a graph of the linearity equation test is obtained, as shown in **Figure 7**.

The results of testing the linearity equation of the voltage on the INA219 GY-219 sensor against the multimeter SANWA CD800a in **Figure 7** show the linearity of the test results is the same as the results of the voltage calibration with an R^2 value of 1 so that the line equation obtained is following the existing data variations. Meanwhile, based on the calculation, the average error rate obtained from the calculation results is 0.034%, so the average sensor accuracy value in reading voltage is 99.96%. The average precision value obtained from the calculation results is 99.97%. Based on the error, accuracy, and precision values obtained, the results of the INA219 GY-219 sensor readings indicate that the sensor can be used to read voltage well.

Table 1. The results of testing the linearity on the voltage of the INA219 GY-219 sensor

***Vref* (V)**	**Voltage on Multimeter (V)**	**Rated Voltage at INA219 GY-219 sensor (V)**					**Average (V)**
		1	**2**	**3**	**4**	**5**	
1.00	1.01	1.01	1.01	1.01	1.01	1.01	1.01
1.50	1.51	1.51	1.51	1.51	1.51	1.51	1.51
2.00	2.01	2.01	2.01	2.01	2.01	2.01	2.01
2.50	2.51	2.51	2.51	2.51	2.52	2.51	2.51
3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
3.50	3.51	3.51	3.51	3.51	3.51	3.51	3.51
4.00	4.03	4.03	4.04	4.03	4.03	4.04	4.03
4.50	4.51	4.51	4.51	4.51	4.51	4.52	4.51
5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
5.50	5.52	5.52	5.52	5.52	5.52	5.52	5.52
6.00	6.06	6.06	6.06	6.07	6.06	6.07	6.06
6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50
7.00	7.02	7.02	7.02	7.02	7.02	7.02	7.02
7.50	7.51	7.51	7.51	7.5	7.51	7.51	7.50
8.00	8.02	8.02	8.02	8.02	8.02	8.02	8.02
8.50	8.50	8.50	8.49	8.50	8.50	8.50	8.50
9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50
10.00	10.02	10.02	10.03	10.02	10.02	10.02	10.02
10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50

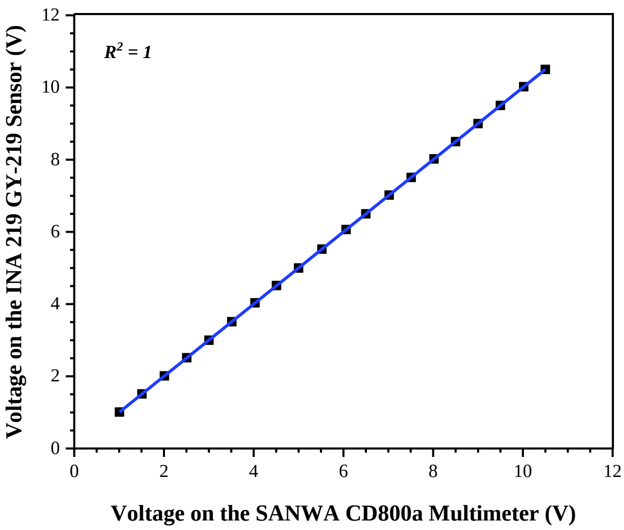


Figure 7. Graph of voltage linearity equation test on the INA219 GY-219 sensor against the SANWA CD800a multimeter

3.3.1 Current Testing on the INA219 GY-219 Sensor

Current testing on the INA219 GY-219 sensor was carried out with the help of a power supply as a voltage source, a load in the form of a 100 resistor and two red LEDs arranged in series, a SANWA CD800a multimeter as a voltage reader, a Heles UX-883 multimeter as a current measurement reference. The current testing mechanism connects the power supply, the SANWA CD800a multimeter, and the Heles UX-883 multimeter with the Vin (+) pin and the Vin (-) sensor. In comparison, the INA219 GY-219 sensor is connected to the Arduino Mega pin and PC/Laptop via the I2C sensor pin and the USB port. Then the current results measured on the INA219 GY-219 sensor will be adjusted to the current results measured on the Heles UX-883 multimeter with a voltage source originating (Vref) from the power supply, which is read on the SANWA CD800a multimeter. There are five repetitions of measurements in the test, where each measurement contains 15 data. The data in the measurement includes a voltage variation of 4–11 V with an interval of 0.5 V for each measurement. The results of the current test on the INA219 GY-219 sensor against the Heles UX-883 multimeter are shown in **Figure 8**.

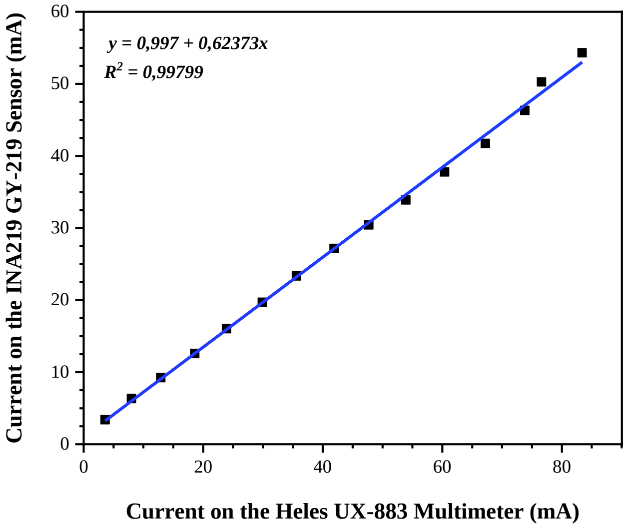


Figure 8. Graph of current testing on the INA219 GY-219 sensor against the Heles UT-883 multimeter

The results of the graph of the current test on the INA219 GY-219 sensor against the Heles UX-883 multimeter in **Figure 8** show the R^2 value obtained is 0.99799 and the linearity equation or linear regression [y = 0.997 + 0.62373x] so that the equation is obtained to get the value current as shown in **Equation 5**.

$$current\ calibration = (current\_mA-0.997)/0.62373 \quad \textbf{(5)}$$

Furthermore, the linearity equation obtained is entered into the device controller program so that the current reading on the INA219 GY-219 sensor matches the Heles UT-883 multimeter. The following is a program for controlling the battery voltage and current parameter monitoring device for reading the current value entered by the linearity equation.

```
float shuntvoltage = 0;
float busvoltage = 0;
float current_mA = 0;
float loadvoltage = 0;
float voltagecalibration = 0;
float currentcalibration = 0;

shuntvoltage = ina219.getShuntVoltage_mV();
busvoltage = ina219.getBusVoltage_V();
current_mA = ina219.getCurrent_mA();
loadvoltage = busvoltage + (shuntvoltage / 1000);
voltagecalibration = (loadvoltage-0.00835)/1.00175;
currentcalibration = (current_mA-0.997)/0.62373;
```

After the linearity equation is entered into the controller program, then re-test is carried out to ensure the error rate, accuracy, and current precision on the INA219 GY-219 sensor based on calculations to match a standard device that has been calibrated. In this case, the Heles UT-883 multimeter. Testing of the calibrated INA219 GY-219 sensor was carried out by providing an input variation of 4–11 V at the load in the form of a 100 resistor and two red LEDs arranged in series. The input variation voltage interval is 0.5 V for each measurement, and each measurement is repeated five times. The results of testing the linearity equation of the sensor current are shown in **Table 2**.

Table 2. The results of testing the current linearity equation on the INA219 GY-219 sensor

***Vref* (V)**	**Current on Multimeter (mA)**	**Rated Current at INA219 GY-219 sensor (mA)**					**Average (mA)**
		1	**2**	**3**	**4**	**5**	
4.00	3.60	3.85	3.85	4.01	4.01	3.17	3.78
4.50	8.50	8.50	8.34	8.66	8.82	8.82	8.63
5.00	13.00	13.47	13.31	13.79	13.47	13.79	13.57
5.50	18.60	18.92	18.6	18.76	18.76	18.44	18.67
6.00	23.90	24.05	24.05	24.37	24.05	24.34	24.18
6.50	29.90	30.47	30.15	30.47	30.15	30.47	30.34
7.00	35.60	35.76	35.92	35.60	35.92	35.76	35.79
7.50	41.90	41.69	42.65	41.37	42.49	42.61	42.16
8.00	47.70	47.62	47.94	48.10	48.10	47.78	47.91
8.50	53.90	53.87	53.55	53.71	54.03	54.03	53.84
9.00	60.40	60.29	60.45	60.77	60.29	60.45	60.45
9.50	67.20	67.98	66.7	67.02	67.18	67.34	67.24
10.00	73.80	73.11	74.08	73.91	74.08	74.08	73.85
10.50	80.60	80.77	80.77	80.23	80.45	80.85	80.61
11.00	87.40	87.26	87.74	87.74	87.38	87.38	87.50

The current test results on the INA219 GY-219 sensor are then compared with the current measurement results that are read on the Heles UT-883 multimeter so that a linearity equation test graph is obtained, as shown in **Figure 9**.

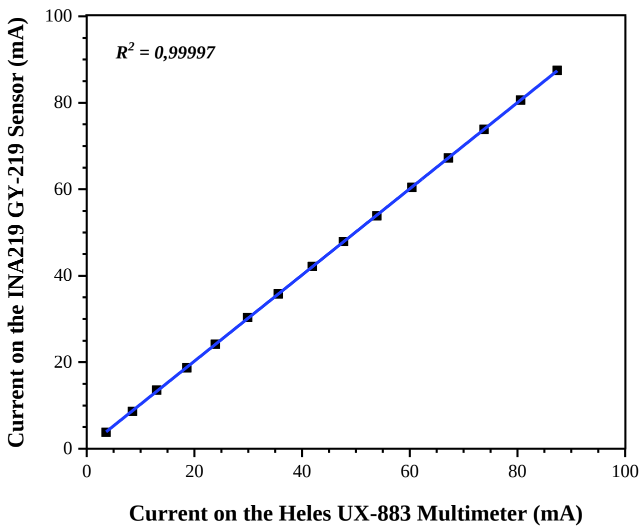


Figure 9. Graph of the current linearity equation test on the INA219 GY-219 sensor against the Heles UX-883 multimeter

The results of testing the equation of current linearity on the INA219 GY-219 sensor against the Heles UX-883 multimeter measurement in **Figure 9** shows that the current reading on the INA219 GY-219 sensor has good linearity with an R2 value of 0.99997. Meanwhile, based on the calculation, the average error rate is 1.608%, so the average sensor accuracy value in reading current is 98.39%, and the average precision value obtained from the calculation results is 98.98%.

3.3 Device Specification

Based on several vital components used to make battery voltage and current parameter monitoring devices such as Arduino Mega XPro 2560 R3, INA219 GY-219 sensor, switching power supply, XL4015 module and load using two lime resistors 1 W 5.6 Ω with HPL 1 W which is arranged in series, it can be seen the specifications of the voltage and current parameter monitoring device for the battery as shown in **Table 3**.

Table 3. Specification Device

No	Specification	Description
1.	*Arduino Device Port Voltage Supply*	6–12 V DC
2.	*Circuit Port Voltage Supply Device Charge*	220 V AC
3.	*Device Charge Voltage Output*	1,25–32 V DC
4.	*Device Charge Current Output*	Maximum 5 A
5.	Battery voltage that the device can discharge	2,4–12 V DC
6.	Battery current that the device can discharge	Maximum 750 mA
7.	Device Resolution	Adjusted Maximum ±1 s
8.	Device Accuracy	98,39–99,96%
9.	Device Operating Temperature	-40°–+85°
10.	Battery Types That Can Be Tested On The Device	Single Cell Battery

3.4 Device Test Results

Device testing is done by connecting the input (+) and (-) of the realized device to the (+) and (-) poles of the battery and connecting the Arduino port and the charge circuit port on the device to the power source, as shown in **Figure 10**.

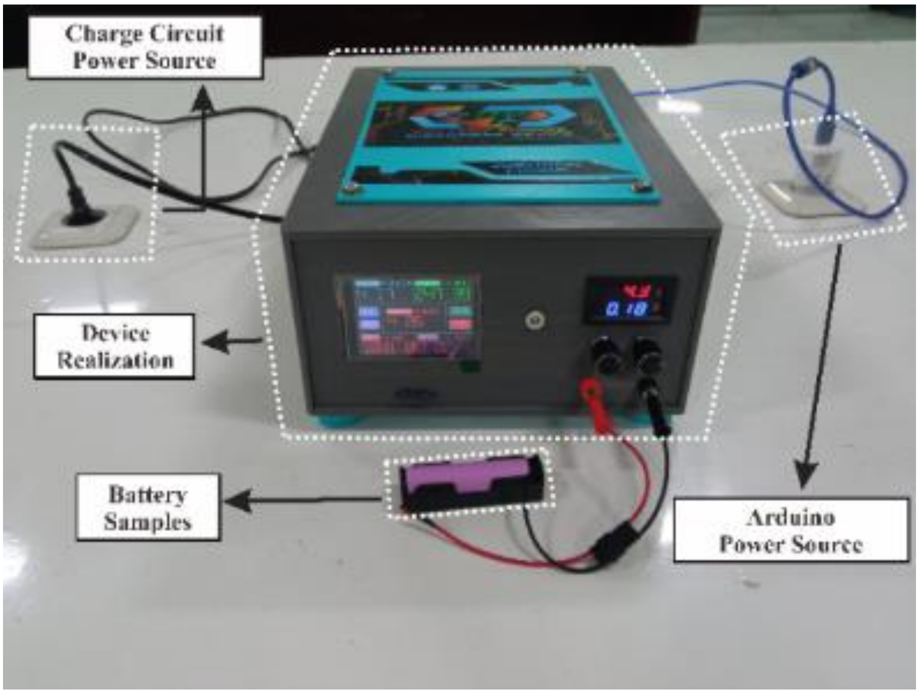


Figure 10. Implementation of device testing

Figure 10 shows the implementation of a device test to monitor a Li-Ion battery's voltage and current parameters in real time in the charge and discharge process using the INA219 GY-219 sensor inside the device. Before being connected to the battery and a power source to activate it, the device has been added with a control program via a device microcontroller in the form of an Arduino Mega XPro 2560 R3 with the help of the Arduino IDE software. The control program is added by uploading the Arduino IDE controller program on the Arduino Mega XPro 2560 R3, which is connected to the PC/laptop COM6 serial port by selecting a baud rate of 115200. When the device is used to monitor battery voltage and current, the controller program commands the 3.2-inch TFT LCD ILI9341 to bring up several displays that the user must select, as shown in **Figure 11 (a)–(c)**.

Figure 11 (a). Main menu display

Figure 11 (b). Monitoring Display

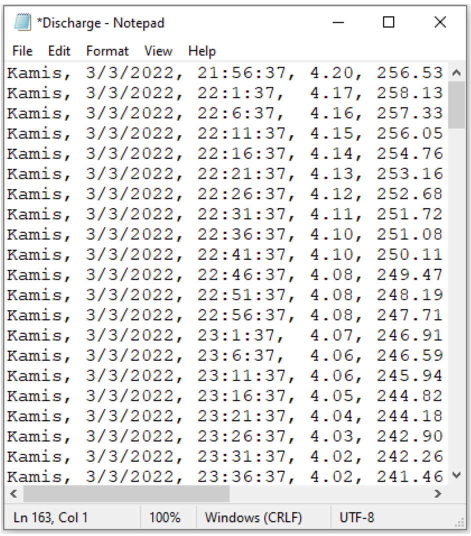
Figure 11 (c). Advanced menu display

Figure 11 (a) shows the main monitoring menu display on the 3.2-inch TFT LCD ILI9341. The main menu display includes the DISCHARGE and CHARGE menus. When selecting a menu, either DISCHARGE or CHARGE, the LCD will direct to the next display, the monitoring display, as shown in **Figure 11 (b)**. In the monitoring display, the user is only required to select the START menu, and the other menus are deliberately set not to be enabled to perform specific commands. After selecting the START menu, the LCD will display the advanced menu, as shown in **Figure 11 (c)**. There are two menu options in the advanced menu display, namely START FROM 0 and CONTINUE. When selecting the START FROM 0 option menu, the monitoring process will start from 0 or at the initial state of the battery when it is tested for the first time. Meanwhile, if it selects the CONTINUE menu, it means that the monitoring process is carried out by continuing the monitoring process that was last carried out.

When selecting one of the menu options, either START FROM 0 or CONTINUE in the DISCHARGE main menu. Relays 1, 2, and 4 will automatically be ON, and relay three will be OFF. The activation of relays 1 and 2 makes the INA219 GY-219 sensor, battery, and load connected so that the discharge circuit becomes active and the process of monitoring battery voltage and current parameters during the discharge process can take place. Then the activation of relay 4 causes the AC power source to be connected to the switching power supply. The DC fan also becomes active when the switching power supply is connected to an AC power source.

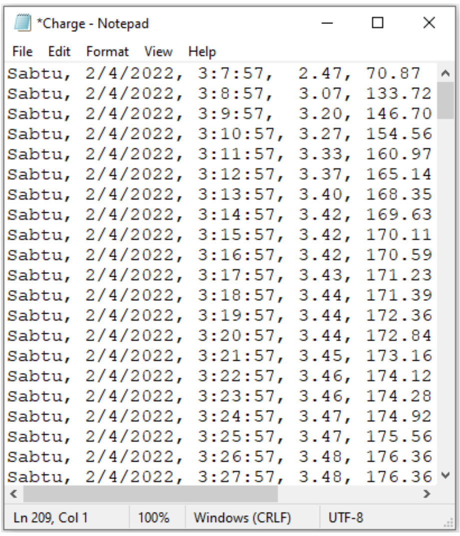
Meanwhile, when pressing START FROM 0 or CONTINUE in the CHARGE menu, relays 3 and 4 will automatically be ON, and relays 1 and 2 will be OFF. The activation of relays 3 and 4 allows the switching power supply to activate the DC fan and the XL4015 module connected to the battery, buzzer circuit, multiturn potentiometer, and digital volt & amp meter. Thus, the circuit in the device charge becomes active, making the battery charge process. The data from the charging process on the battery will be monitored for voltage and current parameters once every minute with the help of the INA219 GY-219 sensor using the same method as activating the discharge circuit. In addition, the LCD will again show the monitoring display as before. However, the difference is that this display will show the monitoring voltage and current according to the results of monitoring readings carried out by the INA219 GY-219 sensor. Then the menu that completes the display can also be used according to the functions determined based on the controller program created.

Suppose the monitoring display has started to show the monitoring result numbers. In that case, the device has started operating to monitor the battery voltage and current parameters according to the user-selected process. Simultaneously, the monitoring result data from the selected process is automatically stored on the micro SD card contained in the device in txt format. When the device is implemented to monitor the voltage and current of a Li-Ion battery during the charge and discharge process, the data obtained from monitoring the voltage and current of a Li-Ion battery are stored in the device as shown in **Figure 12 (a)** and **Figure 12 (b)**.



*Discharge - Notepad
File Edit Format View Help
Kamis, 3/3/2022, 21:56:37, 4.20, 256.53
Kamis, 3/3/2022, 22:1:37, 4.17, 258.13
Kamis, 3/3/2022, 22:6:37, 4.16, 257.33
Kamis, 3/3/2022, 22:11:37, 4.15, 256.05
Kamis, 3/3/2022, 22:16:37, 4.14, 254.76
Kamis, 3/3/2022, 22:21:37, 4.13, 253.16
Kamis, 3/3/2022, 22:26:37, 4.12, 252.68
Kamis, 3/3/2022, 22:31:37, 4.11, 251.72
Kamis, 3/3/2022, 22:36:37, 4.10, 251.08
Kamis, 3/3/2022, 22:41:37, 4.10, 250.11
Kamis, 3/3/2022, 22:46:37, 4.08, 249.47
Kamis, 3/3/2022, 22:51:37, 4.08, 248.19
Kamis, 3/3/2022, 22:56:37, 4.08, 247.71
Kamis, 3/3/2022, 23:1:37, 4.07, 246.91
Kamis, 3/3/2022, 23:6:37, 4.06, 246.59
Kamis, 3/3/2022, 23:11:37, 4.06, 245.94
Kamis, 3/3/2022, 23:16:37, 4.05, 244.82
Kamis, 3/3/2022, 23:21:37, 4.04, 244.18
Kamis, 3/3/2022, 23:26:37, 4.03, 242.90
Kamis, 3/3/2022, 23:31:37, 4.02, 242.26
Kamis, 3/3/2022, 23:36:37, 4.02, 241.46
Ln 163, Col 1 100% Windows (CRLF) UTF-8

(a)



*Charge - Notepad
File Edit Format View Help
Sabtu, 2/4/2022, 3:7:57, 2.47, 70.87
Sabtu, 2/4/2022, 3:8:57, 3.07, 133.72
Sabtu, 2/4/2022, 3:9:57, 3.20, 146.70
Sabtu, 2/4/2022, 3:10:57, 3.27, 154.56
Sabtu, 2/4/2022, 3:11:57, 3.33, 160.97
Sabtu, 2/4/2022, 3:12:57, 3.37, 165.14
Sabtu, 2/4/2022, 3:13:57, 3.40, 168.35
Sabtu, 2/4/2022, 3:14:57, 3.42, 169.63
Sabtu, 2/4/2022, 3:15:57, 3.42, 170.11
Sabtu, 2/4/2022, 3:16:57, 3.42, 170.59
Sabtu, 2/4/2022, 3:17:57, 3.43, 171.23
Sabtu, 2/4/2022, 3:18:57, 3.44, 171.39
Sabtu, 2/4/2022, 3:19:57, 3.44, 172.36
Sabtu, 2/4/2022, 3:20:57, 3.44, 172.84
Sabtu, 2/4/2022, 3:21:57, 3.45, 173.16
Sabtu, 2/4/2022, 3:22:57, 3.46, 174.12
Sabtu, 2/4/2022, 3:23:57, 3.46, 174.28
Sabtu, 2/4/2022, 3:24:57, 3.47, 174.92
Sabtu, 2/4/2022, 3:25:57, 3.47, 175.56
Sabtu, 2/4/2022, 3:26:57, 3.48, 176.36
Sabtu, 2/4/2022, 3:27:57, 3.48, 176.36
Ln 209, Col 1 100% Windows (CRLF) UTF-8

(b)

Figure 12. (a) Data from monitoring the voltage and the current of the Li-Ion battery during the discharge process, (b) Data from monitoring the voltage and current of the Li-Ion battery during the charging process

From the data from monitoring the voltage and current parameters of the Li-Ion battery above both in the charge and discharge process, it can be said that the device made can be used to monitor the battery voltage and current parameters as it should and can work automatically according to the controller program created and device design.

The device can perform the charge and discharge process automatically according to the selected LCD menu display. In addition, the device is also able to read real-time monitoring time data and can store and display monitoring data automatically.

4. Conclusions

The manufacture of a device for monitoring voltage and current parameters of rechargeable batteries in real-time using the INA219 GY-219 sensor, which can be used during the charge and discharge process, was successfully made using the Arduino Mega XPro 2560 R3 microcontroller. The controller program has been successfully created so that the device can work according to the design of the device's manufacturer. The INA219 GY-219 sensor used in the device is capable of reading voltages with an average accuracy rate of 99.96%, an average error of 0.034%, and an average precision of 99.97%; As for reading current, the INA219 GY-219 sensor used in the device has an average accuracy rate of 98.39%, an average error of 1.608%, and an average precision of 98.98%.

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