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Prototype of battery monitoring system for gasoline vehicle using microcontroller module

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Abstract

The condition of the battery in the gasoline vehicle is very important to know because if the condition of the battery has decreased or is not good then it would not be able to start the car engine in the initial ignition phase. The objective of this research is to obtain a battery condition monitoring system on a gasoline car by using a microcontroller-based system. The monitoring system was developed by using research and development method and employing off the shelf components available in the market. The obtained monitoring system was tested on a laboratory scale as well as on an actual gasoline car battery. Laboratory-based and actual environment test results showed that the system was able to measure temperature and voltage well, which has an average difference of 1.058% and 1.010814787% when compared to the measurement results using a commercial thermometer and voltmeter respectively. The system worked stable without any drastic results change. The obtained system could be useful for automotive and transportation areas where the driver will be able to know the battery condition continuously for daily usage and preventive maintenance.

Keywords

Battery monitoring system, Gasoline vehicle, Microcontroller

Introduction

A battery is a direct current (DC) type power source that is used in gasoline, hybrid, and electric vehicles. Currently there are two types of battery used in vehicle application namely lithium-ion based and lead acid-based batteries. Although lithium-based battery offers longer lifetime and higher capacity compared to lead acid-based battery [1], lead acid-based battery is still widely used in automotive industries because it has lower price [2]. In electric vehicles, the battery is the main power source of the vehicle [3] while on petrol-powered vehicles the battery is used in the process of starting the engine (ignition), and turning on facilities such as the lights, air conditioner (AC), audio video, and horn. Battery performance could face degradation because of many factors [4]. If the battery's performance decreases, then it is no longer be able to provide sufficient electrical energy to ignite the vehicle's engine. If this condition occurs on a motorcycle,

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the engine can still be turned on by using manual ignition with a kick starter, but if this condition occurs in a car, the car must be pushed to ignite the engine because the car does not have a kick starter.

In lead-acid batteries, there are two kinds of batteries available in the market involving batteries which have an indicator from which its condition could be known by observing its color directly and batteries without condition indicator so that the driver has to measure voltage of the battery to know its condition. In the laboratory scale approach, the condition of the battery which also called as State of Health (SOH) or any other terms could be known by using techniques such as Electrochemical Impedance Spectroscopy (EIS) [5][6], and impedance measurement [7]. Moreover, battery's SOH mathematically could be analyzed by using approaches such as nonlinear estimator model [8][9], deep learning neural network-based algorithm [10], machine learning of neural network ensemble [11], and combination of EIS and neural network [12].

In daily life, the condition of the battery on a vehicle can be checked by manual measurement using a multimeter to measure the terminal voltage and current. This method is only effective at home or in the workshop when the vehicle is being serviced. If the battery performance decreases during the trip and the vehicle's user is not aware of it then it would make a problem for example the vehicle's engine could not be re-ignited after stop. In the practical experiment perspective, the battery condition could be diagnosed by identifying the fault of the battery's cell [13], measuring its temperature, humidity and electrolyte level [14]. However, these techniques could not be implemented in the battery of the vehicle directly. In general, the condition of the battery on duty in a vehicle could be known by measuring its quality parameters which include the voltage between terminals, current, and temperature [15]. Of these parameters, the terminal voltage is the main parameter that indicates whether the battery is still in good condition [16] and also can be used as the early sign of its failure [17][18].

The most common indicators found in a gasoline car dashboard are including engine revolution, engine temperature, velocity (speedometer), odometer, and gasoline tank level. Continuous monitoring of the condition of the battery on a motorcycle or car allows the user to know the condition of the battery such as detecting a performance decrease of the battery and then carrying out maintenance so that it remains in good condition. Considering the difficulty of starting a car engine compared to starting a motorcycle engine when the condition of the battery has decreased, the system for monitoring a car's battery was proposed in this article. This proposed monitoring system will complement the standard monitoring indicators currently available in the gasoline car's dashboard. The problem to be solved in this publication is how to continuously monitor the condition of the battery on the car when the battery is operated on a daily basis. Microcontroller based system was effective when used for monitoring variables such as water level [19]. Based on this, in this article microcontroller was proposed to be used for battery monitoring. The purpose of this research is to continuously monitor the condition of the car's battery during daily operations using a microcontroller-based system.

Method

System Design

The monitoring system architecture designed in this article is expressed in a block diagram depicted in Figure 1. The Arduino nano microcontroller receives and reads voltage and battery's temperature data by reading the voltage divider circuit and DS18B20 temperature sensor respectively. Temperature of the battery is very important to measure because the battery performance is influenced by its temperature [20]. Furthermore, the temperature of the battery's pack in the automotive application should be tracked [21]. The received data were then processed and displayed on the I2C OLED 128x64 display which is located separately from the main circuit because in the implementation scenario this viewer will be placed on the car dashboard. The buzzer/alarm is used as a warning when the battery is in critical condition, namely the voltage has dropped to a level where it is unable to start the car engine again.

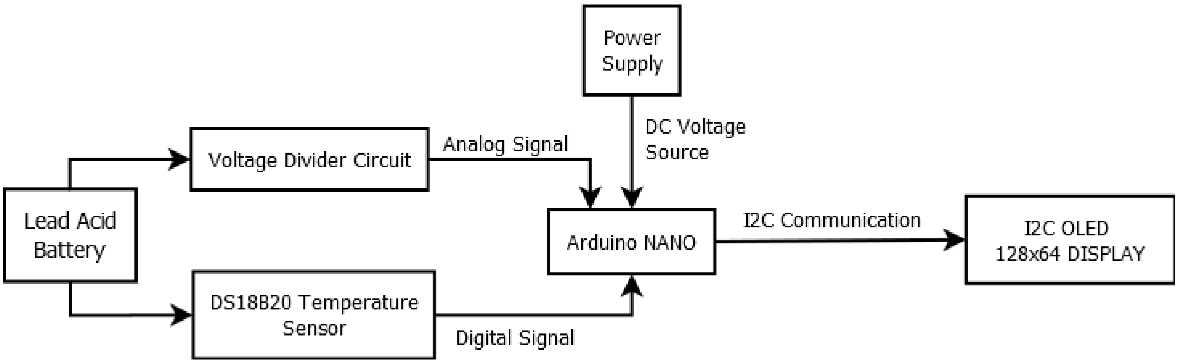

Figure 1. Block diagram representing the general architecture of the developed monitoring system

Hardware Design

The system architecture shown in Figure 1 was then implemented in a hardware circuit as shown in Figure 2. The Arduino Nano microcontroller was used as the main processor. Arduino family is a popular microcontroller which has been used by researchers for example in the smart home applications [22]. The data output of the DS18B20 temperature sensor is in the form of a digital signal which was sent to port D2 of the Arduino Nano microcontroller. The DS18B20 was chosen because it has relatively good performance such as applied in the research in [23]. To measure the battery's voltage, a voltage divider circuit using two 5.1 kΩ resistors was used. The output voltage of this voltage divider circuit was then sent to port A2 of the Arduino Nano microcontroller. Finally for the display part, the SDA and SCL ports on the I2C OLED 128x64 display were connected to the ports A4 and A5 of the Arduino microcontroller respectively. All electronic components get power from the battery.

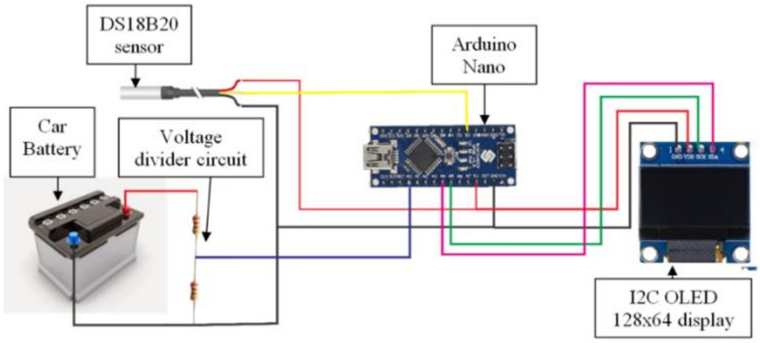

Figure 2. Circuit wiring of the developed monitoring system

Software Design

To be able to process data from the sensor and then to display it on the 126x64 display, the program or software represented by the flowchart in Figure 3 was made on the Arduino Nano microcontroller. The stages of the computing process on the Arduino Nano microcontroller can be described as follows. After the entire hardware circuit is turned on and the initialization process was completed, the microcontroller reads data from the output of the voltage divider circuit. The Arduino Nano microcontroller has an Analogue to Digital Converter (ADC) component which then converts the incoming analog voltage to the microcontroller into a digital signal. This digital signal was then computed and returned into the form of voltage value. The next stage was that the microcontroller read data from the DS18B20 temperature sensor which was in the form of digital data and then computed it back into the temperature value form. The calculated temperature and voltage values were then displayed on an OLED 128x64 display. The last computational stage was the microcontroller checks whether the measured voltage was below the critical value or not, if the voltage value was below the critical value, then the microcontroller will turn on a buzzer or warning alarm. This buzzer feature will be useful for car owners or users so they know that the battery of the car has decreased and needs maintenance or maybe even replacement.

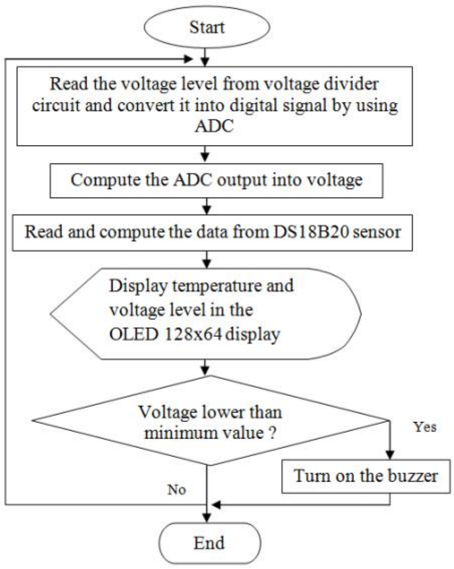

Figure 3. Flowchart of the overall computing process

Results and Discussion

Obtained System

The implementation scenario of the proposed monitoring system was the temperature sensor was placed in the engine room connected to the monitored battery and the hardware part including 128x64 OLED display was placed on the dashboard in front of the driver. To protect the hardware circuit from splashing water, the effect of heat on the engine room, and impact of vibration and shock, the entire hardware circuit was placed in a container box. Because in this article the monitoring system obtained was still a prototype oriented towards proof of concept, a plastic box available on the market was used. The plastic box has dimensions of 7.9 cm (length) x 5.15 cm (width) x 2.7 cm (height) with a thickness of 3 mm as can be seen in Figure 4.

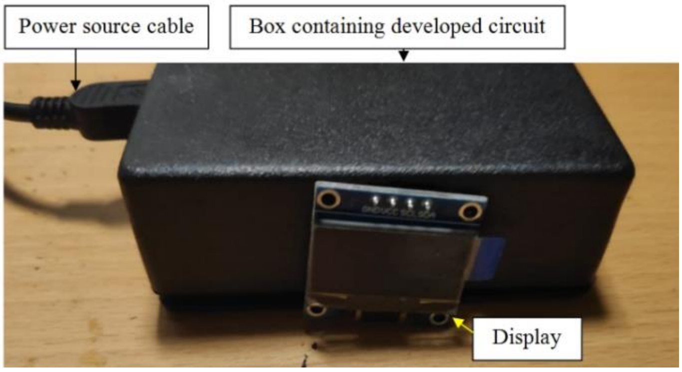

Figure 4. Plastic box used for placing the hardware circuit

Experimentation: Laboratory-Scale Testing (Calibration)

Before being implemented in the actual environment, laboratory scale testing was carried out to find out performance of the obtained monitoring systems compared to the commercial measuring instruments that are widely used by the public. In the test, both the developed system and commercial instrument were used to measure the same object at the same time and their measurement results were recorded for the whole measurement period. In order to compare their measurement results, the measurement difference between the developed system and commercial measurement tools is calculated using equations (1) and (2).

$$\Delta = |c - b| \tag{1}$$

$$\Delta p = \frac{|c - b|}{c} \times 100\% \tag{2}$$

Where c is the measurement result using a commercial measuring instrument, b is the measurement result using the developed system, Δ is the absolute value of the difference between the measurement result with a commercial measuring instrument and the developed system and Δp is the value of the measurement difference in percent. The expected condition is the Δ value should be zero which means that the measurement results by using a developed system are exactly the same as those by using commercial instruments.

Voltage Measurement Testing

Laboratory scale testing for voltage measurement was carried out as follows. The developed system and commercial voltmeter were used together to measure the output voltage of the voltage regulator as a voltage source in the range of 1-14.5 V to model the actual car battery voltage condition. The arrangement of the equipment at the time of testing can be seen in Figure 5. The measurement results by these two devices are then compared and the difference is calculated using equations 1 and 2. There were three times measurement carried out for each voltage value of the voltage regulator's output and these three measurements results were averaged. The measurement results presented in Table 1 showed that the average measurement difference for the entire voltage value is 0.089555556 V or equal to 1.010814787%. The difference in these measurements was considered very small so that the developed monitoring system has the potential to be implemented in the actual environment.

Table 1. The calibration testing result for voltage measurement

Voltage Source (V)	Developed System (V)	Commercial Volt Meter (V)	Difference (Δ) (V)	Difference (Δ) (%)
1	1.1	1.074	0.026	2.363636
2	2.1	2.1	0	0
3	3.1	3.037	0.063	2.032258
4	4.1	4.1	0	0
5	5.1	5.05	0.05	0.980392
6	6.1	6.07	0.03	0.491803
7	7.1	7.06	0.04	0.56338
8	8.2	8.1	0.1	1.219512
9	9.1	9.02	0.08	0.879121
10	10.2	10.09	0.11	1.078431
11	11.1	11.03	0.07	0.630631
11.5	11.6	11.55	0.05	0.431034
12	12.1	12.07	0.03	0.247934
12.5	12.6	12.58	0.02	0.15873
13	13	13.07	0.07	0.538462
13.5	13.4	13.58	0.18	1.343284
14	13.8	14.02	0.22	1.594203
14.5	14.1	14.53	0.43	3.049645

Temperature Measurement Testing

Laboratory scale testing for temperature measurement was carried out as follows. The developed monitoring system and a commercial digital thermometer were used to measure the temperature of the water placed in a vessel. As a comparison material, a mercury thermometer was also used in the measurements test arranged as shown in Figure 6. The display on the 128x64 OLED display consists of two lines, the top row is a display for the measured voltage and the bottom row is a display for the measured temperature. Measurements were taken indoors during the day for 30 minutes and measurement data were recorded every 5 minutes as can be seen in Table 2. The difference in measurement was calculated using equations (1) and (2). The test results presented in Table 2 showed that the temperature measurement results using the developed system have a difference of 0.257 (°C) or equal to 1.058%. This difference was also considered very small so that the developed system has potential to be used in real environments application.

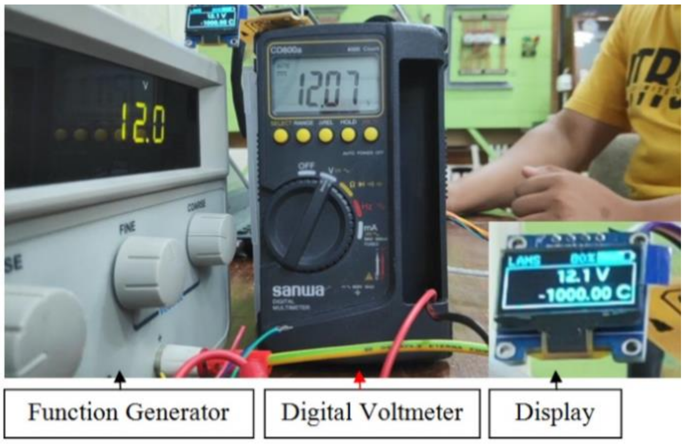

Figure 5. The configuration of experiment in the laboratory: testing the voltage

Table 2. The calibration testing result for temperature measurement

Time at i-th minutes	Developed System (^oC)	Commercial Digital Thermometer (^oC)	Difference ($\lvert\Delta\rvert$) (^oC)	Difference (%)
1	23.8	23.8	0	0
5	24	24	0	0
10	24.2	24	0.2	0.826446
15	24.2	24.5	0.3	1.239669
20	24.3	25	0.7	2.880658
25	24.4	24.7	0.3	1.229508
30	24.4	24.7	0.3	1.229508

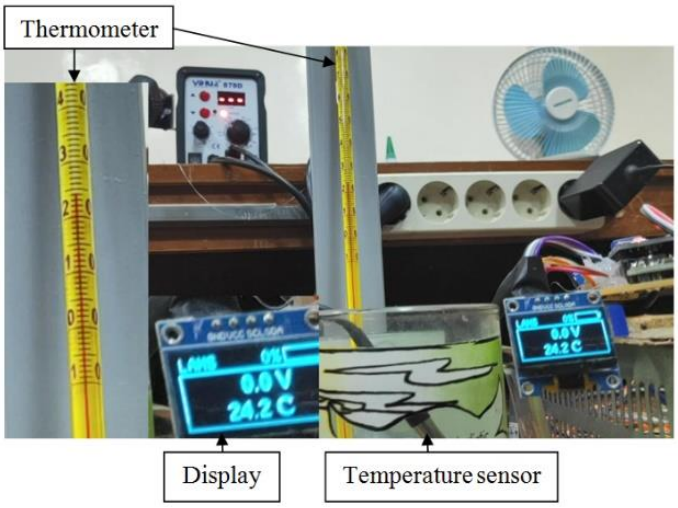

Figure 6. The configuration of experiment in the laboratory: testing the temperature

Actual Environment Testing on a Car

The developed system was tested on a gasoline car which was using a lead acid battery as its power source. The voltage divider circuit was connected to + (positive) and – (negative) of the battery while the DS18B20 temperature sensor was attached at the battery's body as can be seen in Figure 7. The voltage divider and the sensor were then connected to the hardware part placed in the car's dashboard as depicted in Figure 7. The test process was conducted as follows. First, the developed system was used to monitor the voltage and temperature of the battery while the car's engine is still turned off. It can be noted from the measurement test results that the battery's voltage was 11.2 V and the temperature was 28.4 $°C$ the same as ambient temperature. This voltage level was called as the resting voltage value. Secondly, the car's engine was ignited and the engine was kept turned on. The measured voltage level of the battery was increasing in the range between 12.8-12.9 V. This voltage value is called as running voltage value [24]. Furthermore, it can be noted that the temperature value steadily increasing from 28.5 $°C$ in the beginning of car's engine was turned on to 30.5 $°C$ in the end of fourth minutes observation period. The test results also suggested that the measurement results of the proposed system were stable without any sudden change. The test results showed that the proposed system worked as expected, able to monitor the voltage and temperature of the car's battery while on duty in the actual environment. However, the obtained system is only limited to know whether the condition of the battery is good enough to ignite the car engine. This work could be enhanced by monitoring its State of Charge (SOC) and discharge like research results in [25]. Moreover, the monitoring of its SOH will help predict its availability and maintenance requirement [26]. For temperature monitoring, new method of temperature measurement could be further studied, namely not to placed sensor in the battery surface as suggested by [27].

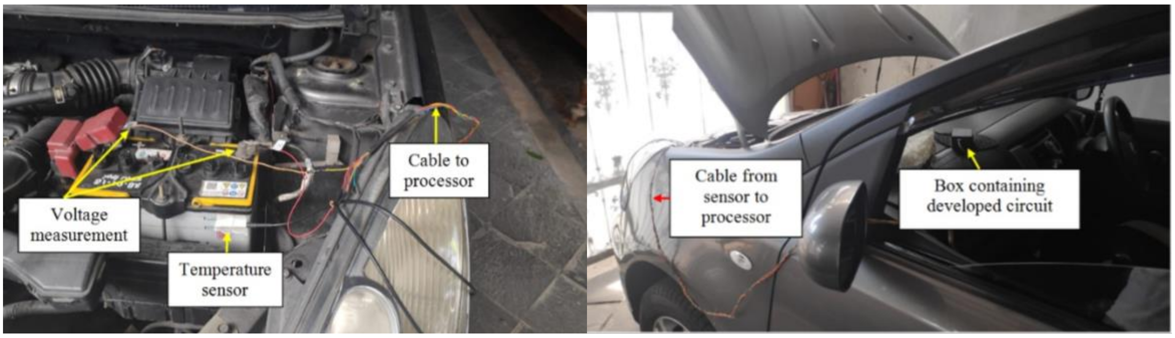

Figure 7. Sensor's arrangement and hardware positioning in the car's dashboard in actual environment testing

Conclusion

Based on the results of the design and testing, it can be concluded that the monitoring system for the quality of electric power, namely the battery in a car, has been successfully developed using commercial electronic components. The test results on the laboratory scale showed that the system is able to measure temperature well, which has an average difference of 0.257 °C or equal to 1.058% when compared to the measurement results using a commercial thermometer. For testing voltage measurements, the developed system has an average difference of 0.089555556 V or equal to 1.010814787%. Furthermore, the actual-environment on gasoline car test results showed that the developed system has stable measurement results without any sudden changes. This research can be continued in various aspects including monitoring its SOC, SOH and finding the best place for the temperature sensor.

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