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Embedded Instrumentation System Using Acquisition Mechanism for BLDC-Powered Electric Vehicle

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ABSTRACT

The primary component of an electric vehicle is the electric motor. In order for the motor to operate properly, some measurement and data acquisition are required for monitoring and controlling its performance. For this purpose, an embedded system is developed and attached to the vehicle. This paper presents the design and implementation of an embedded instrumentation system that includes a data acquisition device, data processor, and data display. A complete prototype-scale electric vehicle was developed and equipped with an embedded instrumentation system. A Brushless DC (BLDC) motor is employed as prime-mover taking power from a 10-Ah Battery. The input parameter is determined by the vehicle's throttle opening, and the output variables are measured and processed. For the purpose of data acquisition, the system relies on Arduino and Raspberry Pi as processing and monitoring devices. The data and information are displayed on the vehicle dashboard to indicate the real-time vehicle performance and some related information. These include speed, power, motor temperature, distance achieved, and estimated distance that can still be reached with the remaining battery capacity. The data and information are graphically and numerically displayed, which would be useful for steering that enhances system efficiency. The system was tested in the lab and real system, where it demonstrated fine accuracy. The average deviations of the electrical data displayed in the instrumentation system with those given by the standard meter are 0.25 Volt, 0.03 Amp, and 0.43 Watt for voltage, current, and power, respectively. From a mechanical standpoint, the average deviations of speed and torque are 1.2876 km/h and 1.218×10^{-4} Nm, respectively. The contributions of this research are the development of a complete system to be operated in real conditions and validation of the displayed information with standard measurement and manual calculation.

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1. INTRODUCTION

People mobility is one of the phenomena related to economic growth and country development. This would be a common challenge in how to enhance people's mobility and, at the same time, reduce congestion, traffic accident, and air pollution. It is reported that urban road transport is the main source of air pollution, which contributes 75% - 85% of pollutant emissions [1]. Therefore, the attempt to reduce gas emissions may be carried out while still letting the people move with their activities. The need to reduce greenhouse gas from the transportation sector may lead to 2 innovations, electric vehicles and car clubs. The last scheme enables fewer car owners, which may lead to less use of fossil fuel. These schemes are expected to enable gas emission control, sustainable development, economic growth, and energy security [2].

Another issue regarding the transportation sector is the dominant use of vehicles or motorcycles powered by fossil fuel-based engines. This sector is indicated to cause intensive consumption of fossil fuels leading to a persistent reduction of fuel deposits. Together with other sectors that also take fossil fuels, the trend of fuel consumption will continue increasing, which causes the fuel deposit to be predicted to finish faster. According to studies on 2019 carried out by international oil companies and independent energy organizations, it is predicted that oil reserves will be depleted in about 50 years. Some developed countries are taking studies on how to completely fulfill the energy demand for electricity, heat, and transportation from renewable energy resources by 2050 [3]. On the other hand, the environmental effects of fossil fuel consumption are another great concern worldwide. The transportation sector seems to be the one responsible for both problems. On the one hand, this sector takes much fuel causing considerable fuel deposit reduction, and, on the other hand, this leads to pollution problems [4]. It would be a dilemma while the transportation sector is required by people, yet it may lead to some drawbacks. Without a strategic intervention, the problem of fuel consumption and CO_2 emission may persist or even rapidly increase [5]. Looking for answers on how the transportation system is operated using resources other than fossil fuel that concurrently implies minimum environmental problems would be the best option in this situation [6].

Electrical energy is expected to be the most feasible type of energy for different use, including transportation systems. This is based on the characteristic of this energy, where it is easy to generate using a different types of resources, and it is extensively suitable for different applications [7]. The use of electrical energy for transportation systems needs a fundamental change in vehicles. The prime mover of the vehicle is replaced with the electric motor, and the energy is stored in a battery [8]. The development of vehicles powered by the electric motor is still in the beginning stage, yet real vehicles are now used and commercially available [9]. However, some researchers are still required to improve the product and how some identified drawbacks may be resolved.

Electric transportation system is a well-researched topic. The topic of this idea is extensive, including policy, simulation, hardware and software development, infrastructure modification, economic analysis, and future development. For the development of the electric vehicle, the topic of research includes the use of motor and the related analyses, controller development, storage and charging strategy, and construction of chassis and body.

Research on the motor application for electric vehicles covers some topics. One of them is the modification of the prime-mover and its further innovation [10] that enables vehicle enhancement for extending the range of driving [11]. Regulating the power supply for the motor leading to enhancing prime mover performance using a new approach is another topic [12]. Vehicle control is a topic that achieves extensive attention ranging from simulation to real application. Control simulation for the electric vehicle includes traction control using conventional control methods [13], controlling the magnetic field to enhance the vehicle performance and efficiency [14], and the development of a control system that enables driving the motor using novel approaches [15]. However, the fewer publication is found in the real implementation of the control strategy for a prototype system [16] as well as for the real system [17].

Another essential issue on an electric vehicle is storage and the related topics. Research on this topic includes material development and modification that may achieve storage advantages [18][19], charging control strategy [20] including the scheme of regenerative braking [21] that allows for maintaining battery life. Physical design is another concern in electric vehicle development. This includes improvement of vehicle safety by introducing an adaptive braking system that avoids antilock conditions [22], a steering control strategy for improving vehicle stability [23], and multi-motor coordination for 4-wheel independently driven (4WID) electric vehicles [24]. The last scheme is further improved by controlling the longitudinal and lateral motion by employing a hierarchical strategy [25]. The body of the vehicle also gets sufficient attention in developing the vehicle. This includes chassis construction that is lighter yet strong, as proposed using aluminum chassis frame instead of using monocoque-steel since it may reduce the weight by more than 60% on vehicle chassis frame [26]. Weight optimization is crucial to extend the battery energy. For the bending, the mortise-tenon joint and reinforced mortise-tenon joint were proposed, which provide high deformation capacities in the reinforced joint [27]. For the vehicle body, sandwich panels using fibber-reinforced plastic with an aluminum honeycomb core in between is one proposed for the vehicle body [28]. The abovementioned innovations enable the electric vehicle to be developed toward a modern transportation system that is economical, safe, reliable, and environmentally friendly.

Driving style is a factor that determines the efficiency of the electric vehicle. This simultaneously achieves the vehicle performance while maintaining minimum energy consumption. A scheme for transforming the automatic control of intelligent electric vehicles into driving style has been proposed [29]. This recognizes the driving style of aggressive, moderate, and conservative in terms of dynamic performance, drivability, and energy consumption. However, for the real electric vehicle, the style of the driver may not be continuously restricted to follow the optimal driving regulation due to some conditions that make the driver has no choice except to adjust the vehicle driving. In this case, the driver should have real-time information about vehicle conditions, which enables him to drive the vehicle to achieve maximum performance with minimum energy consumption [30]. The essential device to provide this information is the instrumentation system. This measures some real-time data and calculates the data to be presented in the vehicle's display system. Data acquisition may also be carried out by this device. The instrumentation system of electric vehicles has not attained sufficient attention in some research, while it may contribute to vehicle driving that enables achieving maximum performance with the highest efficiency.

Based on the aforementioned description, this paper proposes an embedded system for data measurement and acquisition that enables some essential information to be displayed on the vehicle dashboard. The developed system in this research is a completely electric vehicle prototype including a prime mover, controller, power storage, and physical components of the vehicle such as chassis, body, as well as other mechanical parts. In the developed instrumentation system, some sensors are required for measurement purposes. Since some data or information may not be directly displayed from measurement but must proceed with some calculations, a processor is assigned to carry out these processes. The processor receives measured data from sensors and calculates them to result in some necessary information. For measurement and acquisition, the system relies on Arduino and Raspberry pi as processing and monitoring devices. The data and information from both measurement and calculation are presented in a 7-inch LCD display on the vehicle dashboard. These include speed, power, motor temperature, distance achieved, remaining battery capacity, and the distance that can still be achieved for the remaining battery capacity. These data and information are necessary for effective driving leading to maximum performance with the highest efficiency.

This research was carried out in the Electric Car Research Center (ECRC) Universitas Muhammadiyah Surakarta. The developed system has been tested, and the measurement results were benchmarked. By assuming that the measurements from the standard meter are sufficiently valid, these are used as a reference to where the sensor's readings are compared to. It was confirmed that the measurement from the sensors is close to that given by measurement devices. Therefore, the calculation results generated by the processor will also be accurate. This instrumentation system may be further developed to provide more comprehensive information that enables the development decision support system. This may lead to an optimal management strategy under the scheme of Automated Electric Vehicle [31].

2. METHOD

This research was carried out by developing the whole system, followed by some measurements and testing. The instrumentation system is part of the vehicle system. Therefore, for the purpose of testing the instrumentation system, the prototype scale electric vehicle was developed. The measurements were carried out at the laboratory for every module, followed by the real road for the entire vehicle system.

2.1. Electric Vehicle Development

For the purpose of developing the embedded instrumentation system, a prototype-scale electric vehicle was developed. The instrumentation system is part of the vehicle that measures, acquires, processes, and displays the real-time conditions of the vehicle. For developing the vehicle, some components and parts are necessary to be constructed, including the chassis, body, engine, controller, and instrumentation system. The vehicle chassis was constructed with Aluminum Chassis Frame since it offers the advantage of being lighter yet more rigid. The frames were combined to construct the chassis using the method of rivet joint. The vehicle body was constructed using carbon fiber for the reason of its low weight and good mechanical properties [32]. For constructing the vehicle body, two-layer carbon fiber is used. The chassis where some components are installed, and the complete vehicle is shown in Fig. 1.

The developed vehicle is powered by a 48-V Brushless DC (BLDC) motor. This motor is appointed since it is efficient, enables providing high torque, and consumes less power. With the maximum power of 1000 W, this motor enables providing torque of 30 – 50 Nm for the current of 16–18A. This motor draws the power from the 48 V/8.7 Ah Li-ion Battery equipped with 25 A BMS (Battery Management System). The controller used in the system has the specification of 48 V, 5000 W, and 35 A set up for the full feature. The speed of the vehicle depends on the throttle opening determined by the driver that corresponds with the current drawn by the motor. A current limiter is equipped to control the current drawn by the motor that should not exceed the maximum limit. Besides improving system efficiency, this limiter is required to protect components from overcurrent.

For the purpose of data measurement and calculation, a data acquisition system is required. Assessment of electric vehicle performance needs a data acquisition device consisting of a microcontroller and single-board computer embedded in the plant. This is employed to take the data measured by a number of sensors. Some data may be directly presented, but some of them may need further calculation processes to generate information on real-time vehicle conditions. The data are then presented in a graphical user interface using an LCD touchscreen. Hence, some necessary data and information may be required by the driver to determine driving style such that the maximum performance of the vehicle may be achieved while maintaining its efficiency.

(a) (b)

Fig. 1. The vehicle chassis with components (a) and the complete vehicle (b)

2.2. Embedded Instrumentation System

Data Acquisition System is the main instrument of the embedded system employed for taking some data from sensors such as current, voltage, speed, temperature, distance achieved, and other data depending on the requirement. Real-Time Operating System (RTOS) is used as an internal processor in the developed system. RTOS currently achieves growing attention since the development of an embedded system based on a microcontroller. This allows the development of multitasking applications providing deterministic behavior and basic services for inter-task communication. For the developed system, RTOS was used to carry out specific tasks at the determined times [33]. This is called Real-Time Scheduling (RTS) assures that some tasks are done at the given time [34]. For the developed system, this RTS is employed to read data and send it at an accurate time.

Development of an embedded system is carried out by firstly determining the parameters to be measured or calculated. Selection of microcontroller unit and single board computer is the next step according to the prospective parameters to manage. There are some available platforms with different specifications, and this project selected Arduino and Raspberry pi to be utilized. The next step is a selection of suitable sensors depending on the aforementioned parameters. Difference sensors for a different purposes are commercially available. However, there are some concerns regarding the sensor. Precision and durability are important characteristics of the sensors. The sensor may be imprecise since its beginning application, or it was precise but gradually became imprecise after a long time of use. Durability is another feature of the sensor that achieves some concerns in a number of researches. This deals with the ability of the sensor to maintain its characteristics after a long time of application. Due to the need to regularly replace the sensors, the system design should allow doing this job easily.

A graphical device is another part to appoint for presenting the real-time condition of the vehicle. It is a user interface that may be in the form of monochrome LCD, TFT LCD, touchscreen LCD, and mobile phone-connected system. In this project, a 7-in touchscreen LCD is employed. Some features are provided to enable the selection of essential information for guiding efficient vehicle driving.

2.3. Instrumentation System Construction

After developing the vehicle and selecting devices for the embedded instrumentation system, the next step is assembling the instrumentation devices in the existing vehicle. This may be carried out in two steps. The first step is attaching the prime mover and the related supporting components to the vehicle. These include BLDC motor, battery and BMS, controller, throttle, and some supplementary accessories. The layout of components in the vehicle is shown in Fig. 2 that including (1) electric panel, (2) battery, (3) controller, (4) BLDC motor, (5) throttle, (6) touchscreen LCD display, and (7) steering wheel. There are some sensors and measurement devices included in the system, yet they are not shown in the Figure.

The second step is connecting altogether prime-mover components and measurement devices such that the performance of components may be measured. Some parameters may directly be displayed, but others may need further calculations to generate useful information to be presented. For this purpose, it is necessary to use a microcontroller and single board computer to carry out the tasks. As previously discussed, this project employs Arduino and Raspberry pi as the main processor. This system uses 8 Arduinos, 2 voltage sensors, 2 current sensors, 1 hall-effect sensor, 1 temperature and humidity sensor, a speed sensor, and a distance counter. A module of 5V regulated power supply is used in this system. The scheme of the circuit indicating the connection of each component is shown in Fig. 3.

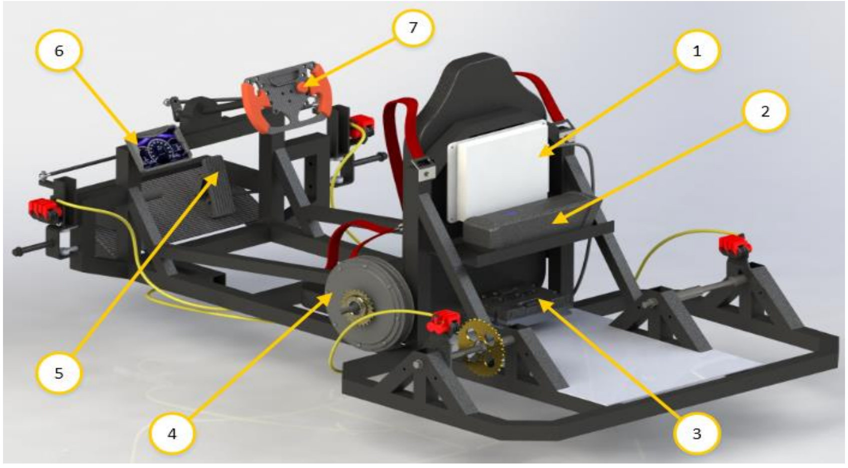


Fig. 2. Component layout in the electric vehicle

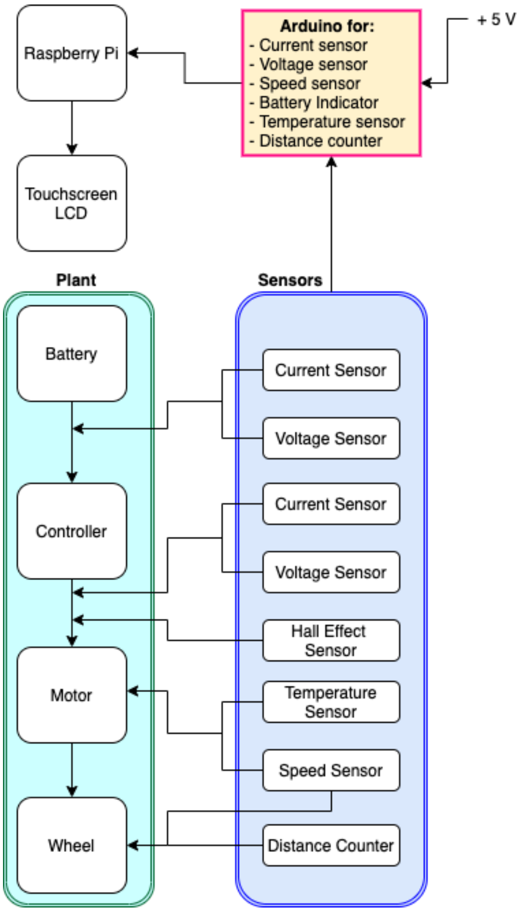


Fig. 3. Connection scheme of embedded instrumentation system for electric vehicle

The input of the system is from the sensor attached to the throttle pedal. It detects a throttle opening level that corresponds to the current drawn from the battery to supply the motor. For the given voltage, this current determines the power supplied to the motor that causes the motor to run at a particular speed. It may also be stated that throttle opening determines the speed of the motor. A number of sensors measure some parameters when the system is running. For voltage measurement purposes, a voltage divider resistor is employed to give a measurable voltage range. For measuring the current, the ACS712–30 Amp sensor is employed. Temperature monitoring is carried out using a DHT11 sensor. The presentation in the 7-inch touchscreen LCD was developed using *myopenlab* to display the graphical and numerical information. This is graphical-based programming from an open-source platform.

2.4. System Testing

The developed system was tested to assure that the electric vehicle prototype might run properly. It was observed that the developed system ran properly while some errors took place for some reason. Some repairs, including components replacement, were necessary to make the system run well. For some assessment steps, measurements were taken from the system while it was operated in the lab and was not driven on the real road. It is considered to be sufficient to measure some data such as voltage, current, and power without driving the vehicle on the road. These data were displayed in LCD and were benchmarked with those given by standard measurement devices. The design of the display and the real display on a 7-in LCD for vehicle instrumentation system is shown in Fig. 4.

(a) (b)

Fig. 4. The display for the embedded instrumentation system (a) the design (b) the picture of the real system

3. RESULTS AND DISCUSSION

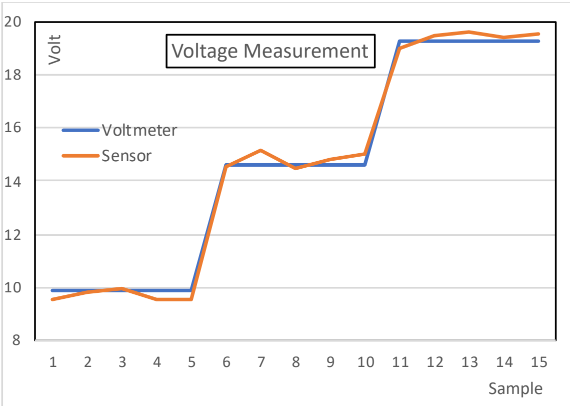
With the complete system in hand, some running tests and measurements might be carried out. This research uses a real system, even at a prototype scale. Some particular research on the electric vehicle was carried out using simulations, such as energy consumption modeling and range estimation [35] and vehicle dynamic modeling and range prediction [36]. There are some suggested concepts for establishing the relation between driving style, weight, and other factors with energy consumption. On the other hand, the relation between the Battery State of Charge (SoC) with the estimated range is still becoming a challenging problem. By using a real system, these relations may be described more realistically. On the other hand, discovering the fact of a real system may support or confirm the simulation results or theory.

As previously described, the instrumentation system was tested to confirm its accuracy. Therefore, there is a requirement to benchmark the measurement results given by the sensors to the measurement given by the meters. The measurements were taken from some conditions, and the results are shown in Table 1. It may be observed that the reading from the sensors is fairly close to that given by meters, while some deviations are identified. Another detail to mention is that the data fluctuation shows the same trend, i.e., the increase or decrease of measurements given by both sensors and meters follows the same inclination.

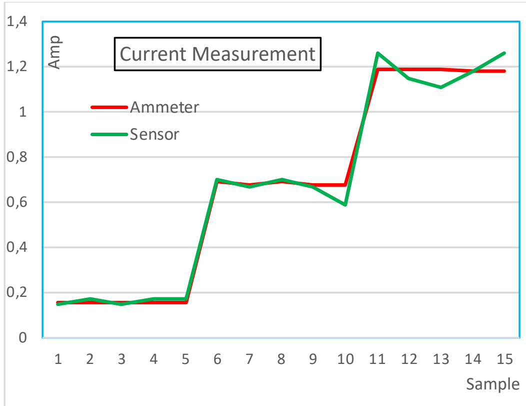
It may be further confirmed from the experiment that sensor reading is more sensitive to any change. A small change of any value has caused the sensor to give different values. Therefore, as can be seen from the table, that sensor reading is more frequent to change compared with that happening in meter. In order to show the comparisons more clearly, graphical presentations are provided. Fig. 5 presents the value of voltage and current, respectively, given by sensor and meter. The figure confirms that the measurement results given by the sensor fluctuate around that given by the meter. It verifies while the results follow the same trend, sensors are more sensitive to the change.

Table 1. The measurement of meters to verify the measurement of the instrumentation system

Sample	Voltage (Volt)		Current (Amp)		Power (Watt)	
	Voltmeter	Sensor	Ammeter	Sensor	Wattmeter	Sensor
1	9.87	9.54	0.16	0.15	1.6	1.4
2	9.88	9.80	0.16	0.17	1.6	1.7
3	9.88	9.98	0.16	0.15	1.6	1.5
4	9.87	9.51	0.16	0.17	1.6	1.6
5	9.87	9.54	0.16	0.17	1.6	1.6
6	14.63	14.57	0.69	0.70	10.1	10.2
7	14.62	15.13	0.68	0.67	9.9	10.1
8	14.62	14.45	0.69	0.70	10.1	10.1
9	14.61	14.84	0.68	0.67	9.9	9.9
10	14.61	15.01	0.68	0.59	9.9	8.9
11	19.30	19.02	1.19	1.26	23.0	24.0
12	19.30	19.51	1.19	1.15	23.0	22.4
13	19.29	19.63	1.19	1.11	23.0	21.8
14	19.30	19.39	1.18	1.18	22.8	22.9
15	19.29	19.54	1.18	1.26	22.8	24.6



(a)



(b)

Fig. 5. Measurement results of meter and sensor for (a) voltage and (b) current

In order to present the power drawn by the system, the instrumentation system uses voltage and current to calculate power. To verify its accuracy, the generated results are compared with those measured by Wattmeter. The results are given in Table 1 and graphically displayed in Fig. 6. It may be observed that while there is a difference between the two, the result of the instrumentation system is acceptable. It again shows that the trend of data change follows the same trend. As expected, the calculation results from the instrumentation system are correct according to the manual verification.

From the results shown in Table 1, the deviation average between the data presented by the instrumentation system with those measured with meter devices is 0.25 Volt (1.84%) for voltage, 0.03 Amp (4.87%) for current, and 0.43 W (3.98%) for Power. Overall, the data of electrical terms presented by the instrumentation system are fairly correct. It should be assumed that the meters provide fine measurement accuracy such that the measurement of instrumentation may be compared.

The verification was further carried out for mechanical standpoints, including speed, consumed power, and torque. For the purpose of speed measurement and verification, the vehicle was driven on the real road, and 5 samples were taken for different speeds. The vehicle speed was measured with a speed sensor, and the obtained result was displayed on the LCD. For comparison purposes, the RPM of the vehicle wheel was also measured using a tachometer. This rpm was converted into speed, taking into account the wheel diameter of 58 cm. It is again assumed that the measurement results given by the tachometer is valid and may be used for benchmarking purpose. Therefore, the data given by the speed sensor were compared with those measured with the tachometer. The comparison is displayed in Table 2 and is graphically presented in Fig. 7. It may be observed that the speed measurement given by both devices is about similar. Some deviations have identified the variation of results yet follow the same trend. From the obtained data, the average deviation of speed measurement is 1.2876 km/h or 4.265%. This may confirm that the result given by the speed sensor is fairly accurate.

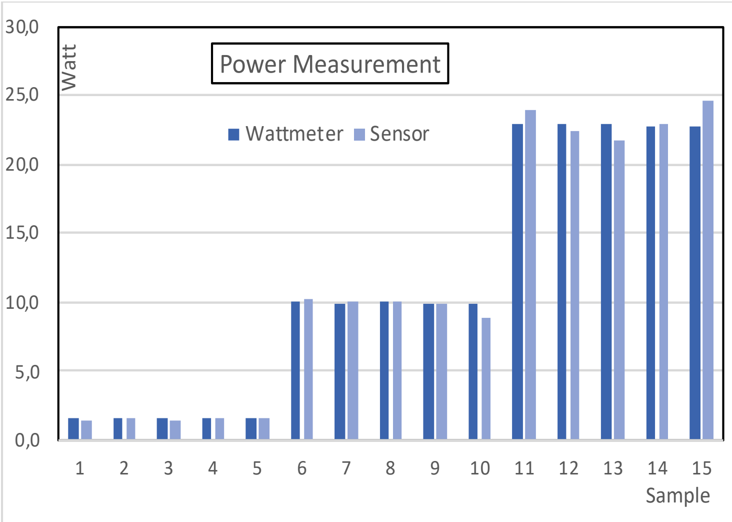


Fig. 6. Power measured device and calculated by the system

Table 2. RPM and speed measurement using tachometer and sensor

Sample	Tachometer		Sensor	
	rpm	Speed (km/h)	rpm	Speed (km/h)
1	138	14.8074	120	12.876
2	248	26.6104	240	25.752
3	412	44.2076	420	45.066
4	730	78.3290	720	77.256
5	916	98.2868	900	96.57

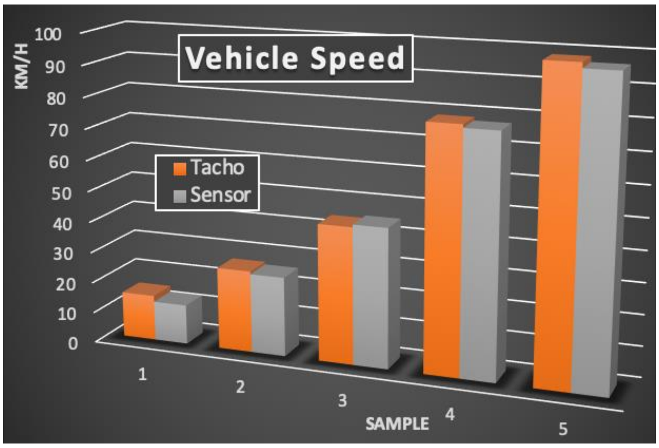


Fig. 7. Vehicle speed measured with tachometer and speed sensor

For recording the distance, which the vehicle has traveled, the wheel rotation number was measured using a hall sensor. This rotation was recorded, and its rotation number was used to calculate the distance taking into account the diameter of the outer wheel. The distance data is updated every 100 m and displayed on the LCD. The distance is continuously accrued to get all the distance covered by the vehicle. The distance data is stored and is accumulated even the vehicle is off.

The power drawn by the vehicle has been previously discussed. This is used to calculate the power (P) in horsepower (hp), and, together with wheel rpm, the torque is calculated. To calculate the power in hp, the following conversion Eq. (1) is used.

$$P(hp) = \frac{P(Watts)}{745.7} \tag{1}$$

For converting the power into torque in N.m., the speed in rpm is necessary, and for this purpose, Eq. (2) is used.

$$T = \frac{30.P}{\pi.rpm} \tag{2}$$

where T is torque in Nm, P is power (Watts), and rpm is the speed in rotation per minute. From the data measured by the sensor as given in Table 2, the related power for every rpm is given in Table 3. The power in hp and the torque displayed in the LCD are given in the table. It may be seen from the table that for a particular rpm, the system may display the power and the torque accordingly. As previously discussed, the power is calculated by multiplying voltage and current.

Table 3. RPM measured by the sensor and related power and torque

Sample	Sensor RPM	Power		Torque (Nm)
		Watt	hp	
1	120	8.5255	0.01143	0.50019
2	240	9.9428	0.01333	0.29167
3	420	8.8559	0.01188	0.14845
4	720	23.9652	0.03214	0.23434
5	900	30.2405	0.04055	0.23656

For verification purposes, manual calculations were carried out to confirm if the information displayed on the LCD was sufficiently accurate. The comparison of the displayed and calculated data are presented in Table 4. It should be noted that the data of rpm used in this case is that measured by the sensor. On the other hand, the displayed power and torque data are obtained through calculations. Table 4 shows that for converting power from Watt (W) into horsepower (hp), the instrumentation system has given accurate results. This is confirmed by manual calculation. However, small differences are identified when the torque displayed in the LCD is checked by manual calculation. The average of these differences is $1.218*10^{-4}$ N.m. (0.038%). While this deviation is sufficiently small, the reason why the deviation appears may be explained. The torque is calculated using real-time measured data of rpm, voltage, and current. These data dynamically change, and when the calculation process presents the result based on the fed data, the new measured data (rpm, voltage, and current) appear. This time delay has caused the difference between the torque displayed in the LCD with respect to that from the manual calculation.

Table 4. RPM measured by the sensor and related power and torque

Sample	RPM (Sensor)	Power (hp)		Torque (N.m)	
		Displayed	Calculated	Displayed	Calculated
1	120	0.01143	0.01143	0.50019	0.50038
2	240	0.01333	0.01333	0.29167	0.29178
3	420	0.01188	0.01188	0.14845	0.14851
4	720	0.03214	0.03214	0.23434	0.23443
5	900	0.04055	0.04055	0.23656	0.23665

The distance that can still be achieved by the vehicle based on the remaining battery capacity is another piece of information useful for the driver. Battery follows time variable and nonlinear characteristics [37]. The relation between voltage and current of Li-ion battery is highly nonlinear. Furthermore, battery capacity reduction is influenced by driving load and operational condition factors. Determining battery capacity is not an easy task. Research on this topic in both theory and practical application is getting sufficient attention that focuses on energy management optimization, life cycle extension, cost reduction, and safe application of the electric vehicle. The classification of estimation method to accurately predict the State of Charge (SoC) of a battery is still becoming interesting discourse covering the algorithm, advantages, drawbacks, and error estimation [38].

There are some approaches available yet are time-consuming and inconsistent with actual experimental data, as well as depending on complicated battery operating and/or aging conditions. The key data for measuring the reduction of battery capacity is the performance degradation of Li-ion batteries [39]. On the other hand, SoC is strongly related to the remaining battery capacity [40]. Hence, the reduction of battery capacity may be considered based on different SoC before and after battery use. In general, SoC may be expressed as the ratio of the remaining battery capacity to the nominal capacity. It is mathematically expressed in Eq. (3)

$$SoC(t) = \frac{Q(t)}{Q(n)} \tag{3}$$

where $SoC(t)$ is the SoC at time t, $Q(t)$ is the remaining capacity at time t, and $Q(n)$ is the nominal capacity given by the manufacturer represents maximum battery capacity [41].

There are some factors influencing battery SoC; taking these into account is challenging. This implies the difficulty of determining the SoC accurately. Some methods may be employed to determine the reduction of SoC due to battery use. One of the methods to determine the SoC reduction is coulomb counting at different SoC [42]. The battery consists of a chemical compound where characteristic changes when the current is drawn to energize the load. This chemical characteristic can be restored by supplying energy to the battery. The battery SoC at a certain condition corresponds to the net coulomb. The simple way to estimate the net coulomb is by measuring the battery's voltage [41].

This paper proposes direct measurement of voltage terminals to determine battery SoC [41]. This method is based on terminal voltage drop due to the battery's internal impedances when it is discharging. Therefore, the EMF of the battery is proportional to the terminal voltage. Since the EMF may be approached to be linearly proportional to battery SoC [38], the terminal voltage may also be considered linearly proportional to the SoC. To provide this information, the full-capacity voltage and lowest-capacity voltage of the battery was measured. From the experiment, the battery voltage when it was fully charged was 56 V and when it was fully discharged, is 36 V. When the vehicle was driven, the reduction of battery voltage was measured to determine the remaining battery capacity and to predict the distance that can be achieved by the vehicle.

It may be noted that driving range estimation is affected by factors such as driving style, weather, traffic, and road infrastructure. To investigate the effect of the factors on energy consumption, a microscopic traffic model was developed to emulate the real condition [30]. However, it seems difficult to determine the influence of each factor on energy consumption clearly. Driving style is expected to be the factor dominantly contributing the energy consumption [29]. However, driving style is about challenging to be exactly correlated with energy consumption since it is strongly related to personal behavior and follows a random pattern. On the other hand, the weight of the vehicle plus the driver's weight will also be the main factor determining the energy consumption.

In this research, the distance that can still be achieved with the remaining battery capacity is predicted based on the battery SoC. As previously discussed, the SoC is equivalent to terminal voltage; hence, the vehicle driving range may be estimated with the remaining battery voltage. By acquiring the progress of voltage reduction, the range estimation may be carried out. This method simplifies the calculation yet comprehensively considers the factors influencing energy consumption, although it does not specify the contribution of each factor to energy consumption.

For the developed prototype, the net weight of a vehicle is 58 kg, and a driver drove the vehicle with a weight of 73 kg. For experimental purposes, the vehicle was driven for 23 laps, each with 450 m. Therefore, the total distance traveled is 10,350 m or 10.35 km. The recorded time to complete the travel was 1171 sec or 19.52 minutes. The test result is indicated in Table 5, and a comprehensive description has been previously discussed. It may be seen from the Table that different time is required for the different lap.

The sampling of battery voltage was recorded to indicate battery capacity reduction. On the other hand, the vehicle energy consumption may also be calculated considering the reduction of battery voltage. At the end of the test drive, the voltage of the battery was measured at 44.35 Volt, which is lower than the initial voltage of 47.54 Volt. This reduction roughly indicates the battery capacity reduction since the vehicle has traveled some distance.

To predict the distance that can still be achieved by the vehicle, the change of SoC equally indicated by the voltage is employed. This describes the relationship between battery capacity reduction and the distance traveled by the vehicle. To estimate the range of travel, the reduction of voltage per-kilometer traveling is firstly calculated, as in Eq. (4)

$$Vs = \frac{\Delta V}{S} \tag{4}$$

where Vs (V/km) indicates the voltage reduction ΔV (V) due to the vehicle traveling for the distance S (km), this measure is updated every 100 m, and the specific figure will be taken into account considering the real condition. The distance that may be achieved may then be estimated by Eq. (5)

$$Se = \frac{Vb - V0}{Vs} \tag{5}$$

where Se is the estimated distance that may be achieved by the vehicle (km), Vb is the current battery voltage (V), and $V0$ is the voltage of the fully discharged battery (V). Since Vs is regularly updated, Se is also updated accordingly. Furthermore, the higher voltage reduction also implies a smaller battery voltage, Vb.

Table 5. The running test of the vehicle and some essential measurements

Lap	Distance (m)	Time (sec)	Energy (Wh)	Battery Voltage Sampling (Volt)
1	450	49	11.1	47.54
2	450	54	11.7	
3	450	52	11.7	
4	450	49	11.7	
5	450	49	11.9	
6	450	50	11.6	
7	450	50	11.5	
8	450	52	11.1	
9	450	50	11.5	
10	450	53	10.7	
11	450	52	11.9	44.95
12	450	51	11.5	
13	450	55	11.8	
14	450	54	11.5	
15	450	51	12.4	
16	450	49	12.1	
17	450	50	11.5	
18	450	49	11.8	
19	450	52	12.1	
20	450	50	12.0	
21	450	50	12.0	
22	450	50	12.0	
23	450	50	11.6	44.35

The aforementioned description indicates that different factors affecting energy consumption lead to different voltage reductions even if the distance traveled is the same. Therefore, to predict the distance that can still be achieved, the previously reached distance and battery reduction are comprehensively considered. The data acquisition enables accomplishing the task. The prediction of this distance is also presented in the LCD display.

4. CONCLUSION

Research on an electric vehicle is extensive, covering almost all aspects of the vehicle. The instrumentation system is one of them that receives less attention. This system presents real-time data and information that enables a vehicle to be driven with both maximum performance and efficiency. Therefore, data and information on vehicle operating conditions must be presented. In the real system, some data may be measured and directly presented, yet some may need further calculation before being presented. For this purpose, a combination of microcontroller and single-board computer is used for measurement and data processing, respectively. Together with some sensors, this combination constructs a data acquisition system that measures, processes, and displays data and information on real operating conditions. This project assigns Arduino and Raspberry pi as microcontrollers and single-board computers that take measurement results from a number of sensors. The instrumentation system is developed as an embedded system and implemented in a vehicle prototype. The accuracy of the presented data is crucial; therefore, they were benchmarked with those given by standard measurement devices. The deviation average between the data presented by the instrumentation system with those measured with meter devices is 0.25 Volt (1.84%) for voltage, 0.03 Amp (4.87%) for current, 0.43 W (3.98%) for Power, and 1.2876 km/h (4.265%) for speed. It may be confirmed that the results of the instrumentation system are fairly accurate based on the benchmarking with those given by the measurement devices or manual calculations. The prediction of the distance that may still be achieved is based on the change of battery SoC correspondingly indicated by the voltage. However, some factors, including driver weight and driving style, influence the change of SoC. This empirical data is taken into account in estimating the distance that can still be achieved with the remaining battery capacity.

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