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On-Road Performance Evaluation of an Electric Vehicle for Battery Consumption and Driving Behavior Detection in Real Operating Conditions of Batu Pahat, Johor

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Abstract: Internal combustion engine (ICE) transportation plays a significant role in air pollution, global warming and harmful to human health. Thus, environmental awareness has led to shifting towards the use of electric vehicle (EV) technology that is much more environmentally friendly. This study analyzes parameters affecting EV's performance in terms of energy consumption. The on-road performance evaluation has recorded parameters such as speed, distance travel, temperature, load factor and battery consumption during multiple road conditions to estimate EV performance in battery efficiency. This study further evaluates the relationships between the acceleration and velocity of the vehicle on different road gradients using a developed motion sensor device. A google sheet with internet of things-based data logger (IOTDL) system was developed to collect acceleration and gyroscope data for driver behaviors such as accelerating, decelerating or turning direction using VibrationData Toolbox by Matlab. Based on the on-road results, battery consumption

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level linearly decreased over trip distance with an almost constant drop rate. With a maximum speed of 60 km/h, the EV can run at a maximum 500 km range per one battery cycle. In addition, the battery consumption increased with increasing speed and load weight over trip distance. Meanwhile, the evaluation also proved that EV saves more energy and fuel cost by 78.8% than an ICE vehicle. Furthermore, road curve with smaller radius and changing direction event tend to accelerate and decelerate repeatedly compared to flat straight road in terms of driving behavior. Thus, this study plays an important role in providing drivers an indicator that helps them to reduce their poor driving habits while encouraging helpful tips to optimize EV energy consumption.

Keywords: Electric Vehicle, Internal Combustion Engine, IOTDL, Energy Consumption, Driver Behavior.

1. Introduction

Transportation nowadays plays a significant role in environmental issues such as air pollution, global warming and greenhouse gas (GHG) emission [1]. Most common vehicles are powered by an internal combustion engine (ICE) fueled by petroleum or gasoline. Improvement of environmental awareness has led to shifting towards electric vehicle (EV) technology that is much more environmentally friendly than ICE vehicles [2]. According to Malaysian Green Technology Corporation (MGTC), switching to EV could save 69% in fuel and 64% in maintenance costs [3].

There are three main categories of EVs which are battery-powered electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and hybrid electric vehicles (HEVs) [4]. Unlike ICE vehicles, an EV is not powered by petrol engines but they are a fully electric vehicle with rechargeable batteries [5]. The energy produced is stored onboard with high-capacity battery packs and uses an electric traction motor for propulsion, thus makes EV a zero carbon emission car. Road vehicle operations are continually monitored by physical parameters such as temperature, air flow and rotational speed. This measurement can be obtained by electronic sensors and transmitted via the internal vehicle communication protocol [6]. The vehicle's performance depends on its battery consumption which may be affected by the battery capacity, weight, speed and driving style, which requires a study to analyze parameters affecting EV's performance in terms of energy consumption.

Nowadays, internet of things (IoT) has become state of art in the current technology of data logging systems. It can assist integrate communication, control and data processing all over different transport systems [7]. It eliminates the disadvantages traditional wired systems, making data measurement and monitoring process more manageable. In this work, on-road performance testing evaluates the four main parameters: speed, temperature, distance travel, and battery consumption. Meanwhile, a developed IoT-based data logger system with sensors monitors the driving behavior data in real-time application.

2. Methodology

Figure 1 shows the flowcharts of the EV on-road performance assessment and data logger with a motion sensor system. For a cyclic on-road performance, three (3) test fields were conducted in real conditions, which include roadway (urban), and highway (short distance), and combined conditions (highway and roadway) using data gathering of parameter displayed on the vehicle's dashboard for energy consumption. The reality in driving conditions is not constant and varies throughout time, meaning that there will exist differences between standardized tests and actual driving experience according to specific regions. Meanwhile, the motion detection system used the accelerometer and gyroscope to monitor the EV through the IoT platform for EV data collection. The on-road evaluation is performed using a BYD e6 EV, a five-seater front-wheel crossover car with a curb weight of 2420 kg and can travel up to 400 km with a single full charge of its iron-phosphate 80 kW battery. The BYD e6 was provided by Perisind Samudra Sendirian Berhad (PSSB).

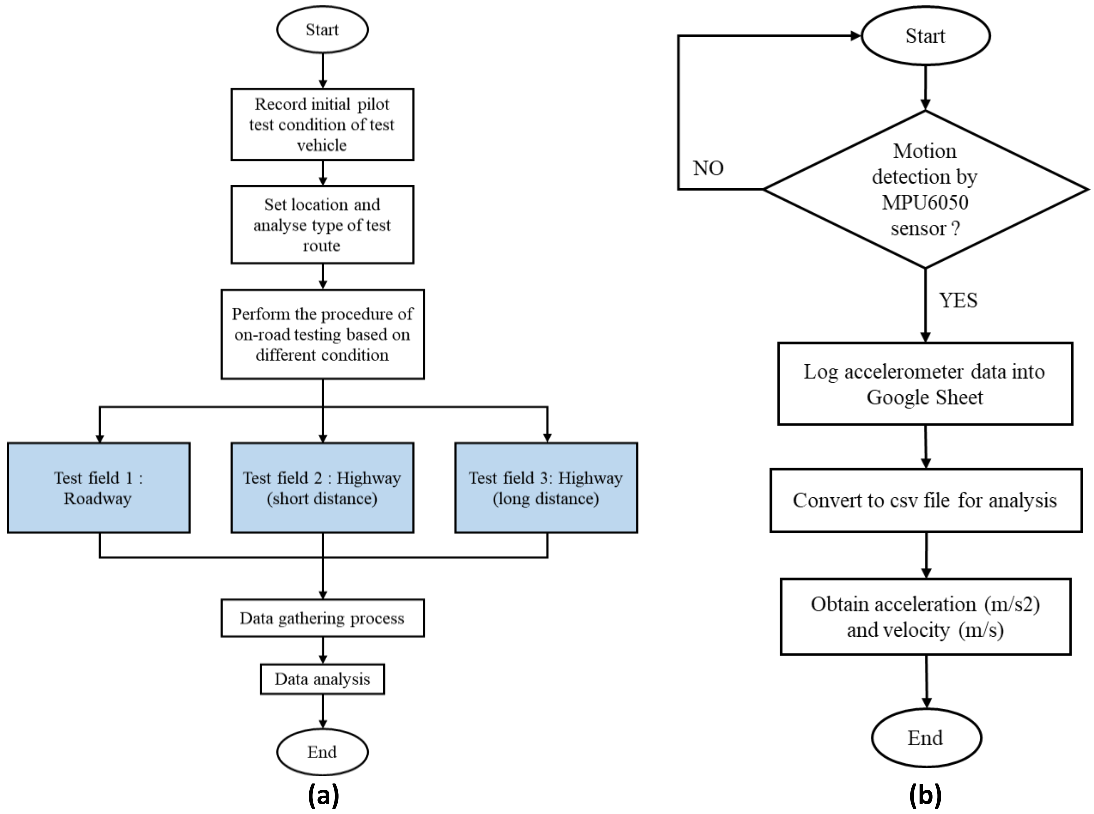

Figure 1: Flowchart of the EV (a) on-road performance and (b) data logger with motion sensor system

2.1 On-Road Evaluation

For different road conditions, the EV is evaluated based on several factors, such as speed, load weight, road condition, and environment temperature, thus generating insight into the mapping of electric driving consumption. All parameters were monitored and manually recorded from the EV dashboard are battery level (%), speed (in km/h), trip (in kilometers), and temperature (in Celsius). For each parameter on test field evaluation, the analysis for battery consumption, estimated maximum range, and energy cost were evaluated for EV and Petrol vehicles. The on-road evaluation was performed on three different test fields: roadway, short-distance highway, and combined conditions (highway and roadway).

(a) Roadway

On-road evaluation of a 40-km distance roadway was performed included both city and rural areas. An estimation of 49 minutes is needed to complete each cycle of the test drive, from Jalan Parit Yani to Kampung Sengkuang, with the following conditions:

i. The speed is maintained within 30 km/h to 60 km/h and is repeated for six cycles to obtain the ambient temperature data at different times. The temperature was monitored with 10-11 am, 12-1 pm, 1-2 pm, 3-4 pm, 4-5 pm, 6-7 pm, and 9-10 pm.
ii. For the same route, the test was conducted in a different constant speed of 60 km/h, 70 km/h, and 80 km/h.

(b) Highway (short distance)

For a 25-km highway, the estimated time to complete the trip is approximately 49 minutes. The continuous driving path is directly from Toll Plaza Ayer Hitam to Toll Plaza Tangkak through Toll Pagoh with the following conditions:

i. The EV's speed was maintained at a variable steady speed of 80 km/h, 90 km/h, 100 km/h, and 110 km/h, for the 90-km highway test.
ii. In an evaluation of load weight, the EV's speed was kept at a constant rate of 90 km/h and 110 km/h. Two load weight of 160 kg and 230 kg was performed during the two different speeds.

(c) Combined conditions (Highway and Roadway)

A continuous long-distance driving from Serdang to UTHM, Parit Raja, using a North-South Plus Highway was performed. As a comparison purpose, a combustion engine vehicle (SUV Proton X-70) was also used during the trip. Both EV and ICE vehicles completed the trip of 242 km for about 3 hours with a constant average speed of 90 km/h at the highway and a range of 50-60 km/h at the roadway upon arriving at Toll Plaza Ayer Hitam until UTHM. As for ICE, petrol consumption was calculated using mileage.

2.2 Motion Detection System

MPU6050 is a tracking device that provides raw data for the three-axis accelerometer and three-axis gyroscope of a moving vehicle. ESP8266 NodeMCU microcontroller sends and logs generated data from an accelerometer into Google sheet IOT cloud over the internet using a Google App Script for real-time application. These collected data can be accessed through desktop and smartphone before exported to a CSV file to analyze acceleration and velocity. Block diagram of the developed motion sensor is depicted in Figure 2.

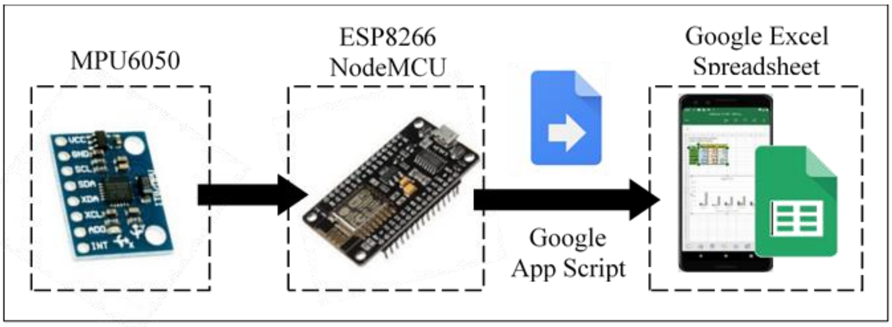

Figure 2: Block diagram of Electric Vehicle Motion Sensor with IOT Based Data Logger system

Figure 3 illustrates the simple circuit configuration of the developed device for the motion detection system. The system aims to estimate driving behaviors, such as accelerating, decelerating, or heading direction changes on different road gradients. Throughout the on-road test, the motion sensor was placed horizontally on the vehicle's dashboard and aligned so that the accelerometer's Y-axis is along the vehicle's moving direction, as shown in Figure 4. An I2C LCD displayed all three axes', X, Y, and Z tilt angle. Acceleration (m/s2) and velocity (m/s) of the moving vehicle due to on-road vibration and motion under different running condition were obtained using the Vibration Data toolbox.

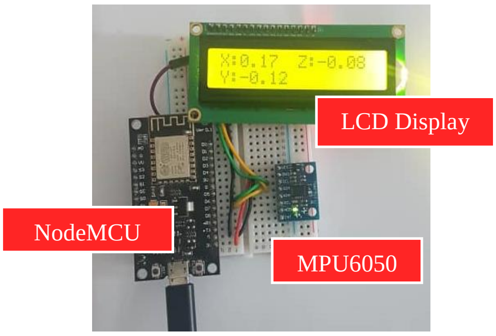

Figure 3: Testing of the Motion Sensor

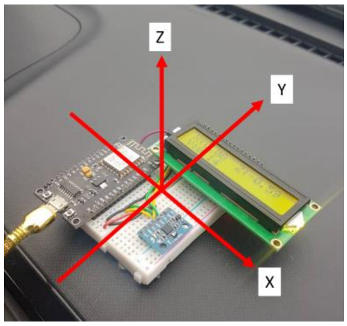

Figure 4: Position of Motion Sensor on vehicle's dashboard

3. Results and Discussion

Three different test field was performed for the evaluation of EV through on-road testing. The first evaluation was analyzed based on the effect of battery drop rate on its battery consumption within six cycles on a roadway condition. Table 1 summarizes the findings for a 40-km roadway at a speed limit between 60 km/h and 30 km/h, depending on the road and traffic conditions. Battery level linearly decreased over trip distance with an almost constant drop rate, and the estimated total trip distance (km) decreased as battery consumption (kWh/100km) increased. Overall, the average drop rate is 0.2 %/km, which equivalent to 16.0 kWh/100km. This indicates that EV can run at a maximum 500 km range per one battery cycle with a maximum speed of 60 km/h. Table 1 lists 6-cycle evaluation results for 40-km roadway.

Table 1: 6-cycle evaluation results for 40-km roadway

Cycle	Average Drop Rate (% / km)	Battery Consumption (kWh/100km)	Maximum range(km)/cycle battery
1	0.2000	16.0	500.00
2	0.2000	16.0	500.00
3	0.2000	16.0	500.00
4	0.2000	16.0	500.00
5	0.2233	17.9	447.8
6	0.2322	18.6	430.7

Table 2 summarizes the findings for a 40-km roadway at a different constant speed. For each constant speed evaluation, the battery consumption increased with increasing speed over trip distance. From the evaluation results, the battery consumption is 16.0 kWh/100km for 60 km/h, 17.9 kWh/100km for 70 km/h and 18.4 kWh/100km for 80 km/h. The maximum range per one cycle battery for 60km/h, 70km/h, 80km/h are 500km, 447km, and 435km, respectively. This data supports the hypothesis that driving at slower speeds is more efficient than high speed.

Table 2: EV evaluation tests for 40-km roadway at a different constant speed

Speed (km/h)	Average Drop Rate (% / km)	Battery Consumption (kWh/100km)	Maximum range(km)/cycle battery
60	0.2000	16.0	500
70	0.2233	17.9	447
80	0.2300	18.4	435

Meanwhile, Figure 5 shows battery consumption over temperature from seven different time range. The time range of 12-1 pm and 1-2 pm has a higher average ambient temperature of 32.9°C and 35.4°. The battery consumption increased with increasing environmental temperature.

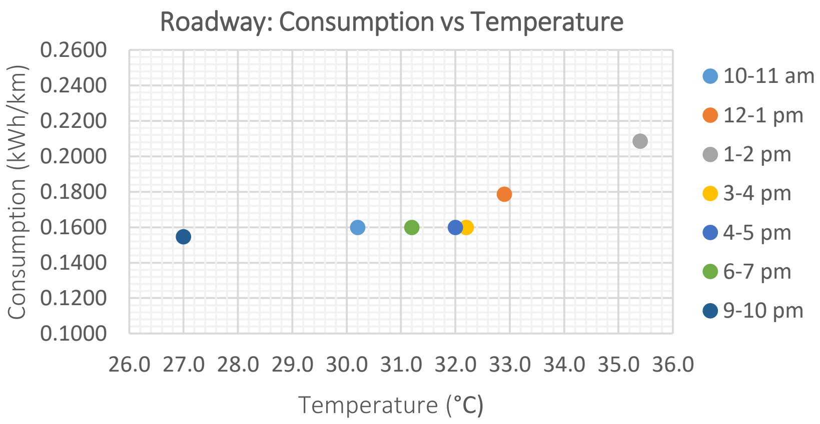

Figure 5: Battery consumption against temperature

The second evaluation was analyzed based on the effect of battery drop rate on its battery consumption for a short distance in a highway condition. Table 3 summarizes the findings for the 25-km highway at various constant speeds. For each constant speed evaluation, the battery consumption increased with increasing speed over trip distance with battery consumption of 17.8 kWh/100km for 80 km/h, 18.3 kWh/100km for 90 km/h, 23.2 kWh/100km for 100 km/h and 24.4 kWh/km for 110 km/h. The maximum range per one cycle battery for 80km/h, 90km/h, 100km/h, 110km/h are 449km, 437km, 345km and 328km, respectively.

Table 3: EV evaluation tests for 25-km roadway at different constant speeds

Speed (km/h)	Average Drop Rate (% / km)	Battery Consumption (kWh/100km)	Maximum range(km)/cycle battery
80	0.2226	17.8	449
90	0.2284	18.3	437
100	0.2899	23.2	345
110	0.305	24.4	328

Table 4 summarizes the findings for 160-kg load and 230-kg load, respectively. Tabulated data shows that the load factor has a significant difference in battery consumption. The battery consumption increased by increasing a 1-kg load in the EV with 0.08 kWh/100km for 90 km/h speed and 0.073 kWh/100km for 110 km/h.

Table 4: Summarize of 160-kg load weight

160 kg		Load Weight	230 kg	
90	110	**Range speed (km/h)**	90	110
25	25	**Total distance (km)**	25	25
0.2284	0.305	**Battery level/distance (%/km)**	0.3009	0.3692
0.183	0.244	**Battery consumption (kWh/km)**	0.241	0.295
18.3	24.4	**Battery consumption/distance (kWh/100km)**	24.1	29.5
437.8	327.9	**Maximum Trip/Battery Cycle**	332.3	270.9

Lastly, the third evaluation was analyzed based on the effect of battery drop rate on its energy consumption for combined conditions of highway and roadway. Battery percentage over time travel is depicted in Figure 6. As the battery was charged to 100% prior to departure from starting location, the battery percentage dropped to 42%. There was an average drop rate of 0.31 % per minute. This indicated that the EV could travel approximately 312.5 to 322.5 km.

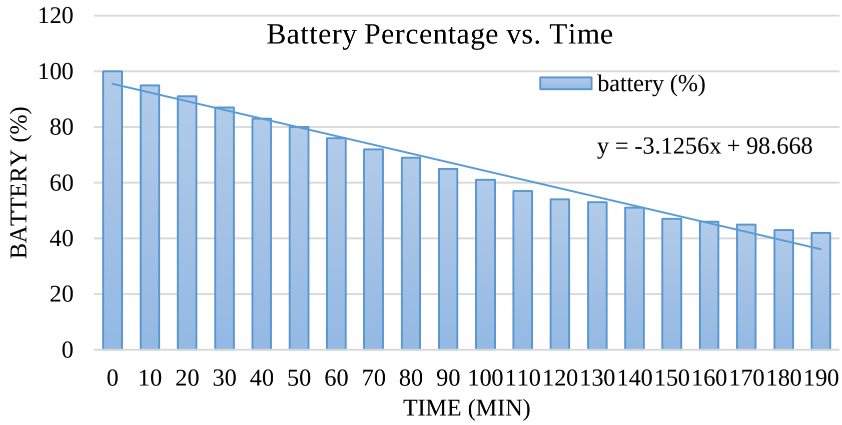

Figure 6: Battery percentage drop over time travel

Table 5 shows the comparison of EV and Combustion Engine. During the 242-km evaluation, EV's energy consumption is 46.4kWh and 18.876 L of fuel by the ICE vehicle. For a comparison purpose, the fuel cost for an ICE vehicle was calculated using the fuel price for RON-97, which is RM2.53/L. Referring to a domestic tariff, the fuel cost savings achieved for tariff A was around 78.8%. This proves that EV has advantages and benefits over the combustion engine.

Table 5: Comparison of EV and Combustion Engine (X70)

EV (BYD-e6)		ICE
90	**Average speed (km/h)**	90
241.6	**Total distance (km)**	242
46.4 kWh	**Energy consumption**	18.876 L
19.20 kWh	**Energy consumption / 100km**	7.8 L
RM4.19 (Tariff A)	**Cost/100 km**	RM19.74

3.2 Evaluation of On-board Motion Sensor

In contrast, the developed motion sensor system used to determine drivers' behavior, such as accelerating, decelerating, or heading direction changes, may impact EV performance. An on-road vehicle test was performed on different test routes considering road grade and traffic conditions to apply the developed system device and obtain a real data set. These studies only focus on acceleration and velocity characteristics at Parit Raja to Ayer Hitam roadway (first test) and Ayer Hitam to Kluang roadway (second test). Throughout these tests, driving behaviors were monitored in terms of accelerating, decelerating, and turning events.

A 15-minutes test was conducted from Parit Raja roadway to Plaza Toll Ayer Hitam with speed maintained at 70 to 80km/h. Figure 7 shows the acceleration and velocity output during the test. Data collected along the extended, straight roadway test shows that the vehicle has a mostly constant acceleration since the traffic condition is clear. The red circle describes how the vehicle is accelerating uphill to a maximum value before decelerating downhill or coast down and stop by the traffic light on the exit junction to Tol Ayer Hitam.

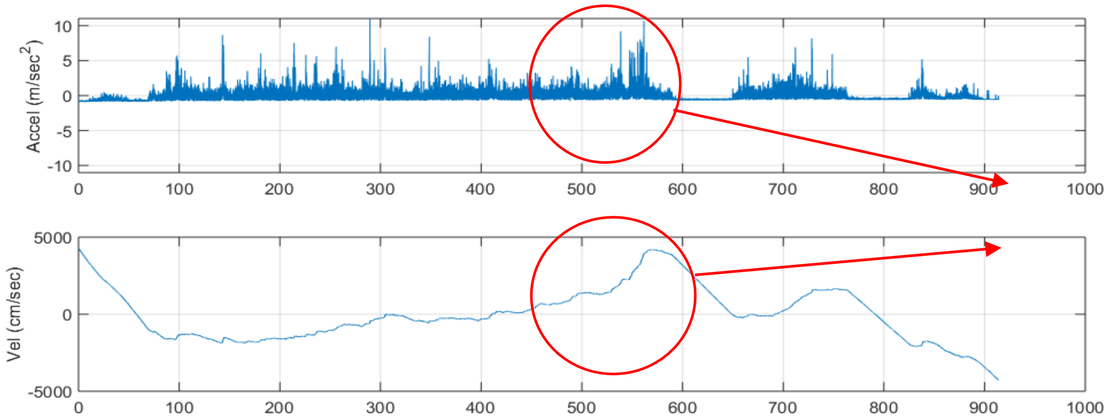

Figure 7: Acceleration, velocity, and displacement along Parit Raja to Ayer Hitam roadway

Meanwhile, the second test was conducted on the main road from Ayer Hitam to Jalan Kluang for about an 8-minute duration. The speed is maintained between 60 to 80km/h. This roadway has fewer small curve radius roads than the first route test. Curve roads are frequently followed by braking and turning. Acceleration and velocity output is presented in Figure 8, where the red circle shows a sharp U-turn event. After decelerating, there is a sharp positive velocity slope and increase in acceleration to achieve the required speed (cruising speed) on the main road.

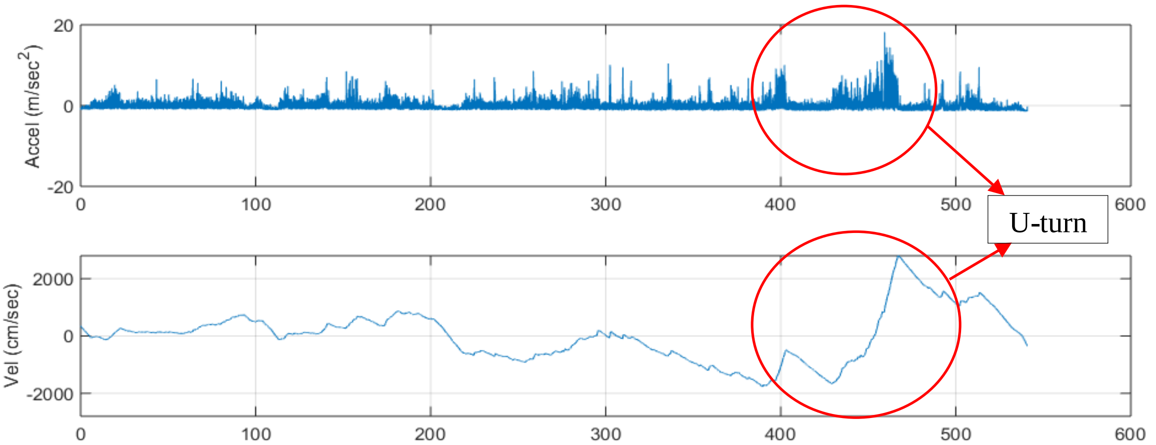

Figure 8: Acceleration, velocity, and displacement along Ayer Hitam bus terminal to JPJ Kluang roadway

The velocity at which the maximum acceleration is achieved and the time is taken to achieve it differs for various roadway types due to their different road grade. The first test was conducted on a flat and straight road. Hence the rate of change of acceleration is not significant. When the vehicle is idle, the driver typically accelerates more and begins to decelerate when the driver needs to bring the vehicle to its target speed level. There would be no acceleration in this situation, as the ideal velocity level was achieved. The significant changes in velocity were observed at the end of the first test due to the road's slope during uphill and downhill movement. Compared to the first test of flat road condition, the second test was performed on the road with more curves with a smaller radius. The tendency to accelerate and decelerates repeatedly is higher in this condition, presented by the frequent slope changes in the velocity graph. Besides the road grade factor, a changing direction event of a vehicle, such as making a U-turn, could also impact the vehicle's acceleration and velocity.

The data from a combination of accelerometer and gyroscope sensors use to examine the travelling and driving mode of the EV by detecting driving activities (i.e. stopping, straight, turning left, turning right) and travelling mode (i.e., driving up and driving down) for improving the accuracy in recognizing driving events and behaviors [8]. Battery efficiency is mainly influenced by vehicle characteristics, road type, traffic condition, and driving pattern or activity [9, 10, 11].

4. Conclusion

In summary, an analysis of the factors and parameters affecting EV performance as a function of battery consumption in real operating conditions is shown by performing multiple on-road testing in the designated road conditions by manual evaluation. As a result, parameters such as trip distance, time, weight, temperature, and speed are proven to affect EV battery consumption. Besides, a comparison with ICE vehicles on their energy usage has also been made. Meanwhile, the developed on-board motion detection system managed to keep track of driving behaviors, such as accelerating, decelerating, or heading direction changes on road grade. The data analysis shows that the inclined road graphs give a more significant fluctuation in acceleration and velocity than a flat road. Statistical analysis should be made in future research to validate the proposed data.

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References

[1] Mande, Hosea. “Review on CO2 Emission from Transportation Sector in Malaysia”. 10.13140, 2015.

[2] Weldon, Peter & Morrissey, Patrick & O’Mahony, Margaret. “Environmental Impacts of varying electric vehicle user behaviours and comparisons to internal combustion engine vehicle usage”. An Irish case study. Journal of power sources. 319. 27-38, 2016

[3] Suruhanjaya Tenaga, “Towards a World-Class Energy Sector Malaysia.” Vol. 12, 2019. [Online]. Available:https://www.st.gov.my/ms/contents/publications/energy Malaysia/ EM12%20Nov%202017%20v2.pdf [Accessed Feb. 18 ,2020].

[4] X. Wu, D. Freese, A. Cabrera, and W. Kitch, “Electric vehicles’ energy consumption measurement and estimation. Transportation Research Part D: Transport and Environment”, 34, pp.52-67, 2015.

[5] C. C. Chan, “An Overview of Electric Vehicle Technology”. In Proceeding of the IEEE, vol. 81, no.9, pp. 1202-1213, Sept. 1993.

[6] D. Rimpas, A. Papadakis, and M. Samarakou, “OBD-II sensor diagnostics for monitoring vehicle operation and consumption”. Energy Reports, 6, pp.55-63. 2020.

[7] C. Perera, A. Zaslavsky, P. Christen and D. Georgakopoulos, "Context aware computing for the Internet of Things: A survey", IEEE Commun. Surveys Tuts., vol. 16, no. 1, pp. 414-454, 1st Quart. 2014.

[8] D.-N. Lu, D.-N. Nguyen, T.-H. Nguyen, and H.-N. Nguyen, “Vehicle Mode and Driving Activity Detection Based on Analyzing Sensor Data of Smartphones,” Sensors, vol. 18, no. 4, p. 1036, 2018.

[9] C. Marina Martinez, M. Heucke, F.-Y. Wang, B. Gao, and D. Cao, "Driving Style Recognition for Intelligent Vehicle Control and Advanced Driver Assistance: A Survey," *IEEE Transactions on Intelligent Transportation Systems*, vol. 19, no. 3, pp. 666–676, 2018.

[10] Qiuwei Wu, A. H. Nielsen, J. Østergaard, Seung Tae Cha, F. Marra, Yu Chen, and C. Træholt, "Driving pattern analysis for electric vehicle (EV) grid integration study," 2010 Innovative Smart Grid Technologies (ISGT), 2010.

[11] C.-H. Lee and C.-H. Wu, "Learning To Recognize Driving Patterns For Collectively Characterizing Electric Vehicle Driving Behaviors," *International Journal of Automotive Technology*, vol. 20, no. 6, pp. 1263–1276, 2019.