Experimental and Analysis of Vehicle Dynamics Performance based on Driving Behavior

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ABSTRACT

Most of the time, the dynamic performances of a vehicle is depending on the driving behavior of the driver. The driving behavior can be analyzed from the way they control the vehicle during cornering, accelerating, braking and driving through uneven roads. This paper presents the vehicle dynamics performance analysis based on driving behavior among teenagers' drivers. The analysis was concentrated on how they handle the vehicle that can be seen from the values of moments consists of roll, pitch and yaw and accelerations (vibrations) at x, y and z axes. From the data collected, the dynamic performances of the vehicle were analyzed based on the driving behavior. It can observed that, the aggressive drivers produced significant values in moments and accelerations especially roll moment and vertical acceleration. Significant values in moments and vibrations can compensate the safety part of the driving and serious accident may occur

Keywords: *Dynamics Performance, Moments, Acceleration, Vehicle Vibration*

Introduction

Driving behavior is the response of the driver actions to control the operation and movement of a vehicle. Many of the dynamic performances of a vehicle is determined by the way the driver drives the vehicle and the active

ISSN 1823-5514, eISSN 2550-164X
Received for review: 2016-09-01
Accepted for publication: 2016-11-17
Published: 2017-01-19

suspension system [1]. Driving is a complex activity that requires a multi-level behaviors. Much of the driving behavior is automatic, a development from experiences and requiring minimal allocations of attention [2][3]. This automatic aspect of behavior is based on mental and psycho programs called Schema. Schema helps us deal with every day driving occurrences such as negotiating traffic, intersections and road conditions [4]. In emergency situations the schema or automatic behavior may not be appropriate and shifting the behavior more consciously to control such rare events is unlikely to succeed because the driver do not have effective emergency behavior or schema, at his disposal [5][6]. Major driving behavior may be classified into aggressive, passive, distracted, alert, ignorant, confident, timid, skilled, arrogant, tolerant, angry, polite and competent [7][8][9]. In this project, LEGO Mindstorms EV3 (EV3) as shown in Figure 1 is used as the DAQ in order to determine the values of the moments and accelerations of a vehicle [10][11][12][13]. The EV3 display is a monochrome LCD 178 x 128 pixels where its main processor is 300 MHz Texas Instruments Sitara AM1808 (ARM9 core). It has a main memory of 64 MB RAM and 16 MB Flash memory with MicroSDHC slot. Additional sensors used are accelerometer and gyros.

Figure 1: LEGO Mindstorms DAQ and sensors.

Methodology

Weighing

Figure 2 shows the car is being weighed. The car is weighed in order to find the center of gravity (COG). The COG is the location where the EV3 will be attached. The car is being weighed at each tire to get the total weight of the vehicle using the load sensor. Four load sensors is being placed under each tire of the vehicle. There are two conditions in measuring the weight, one is the standard flat condition and another one is at inclined condition. The data from load sensor is converted by using DASYLab software. The data about

the weight of the vehicle is collected and it is used to find the COG theoretically

Figure 2: Equipment set up for car weighing.

Experiment

10 students are selected randomly to do a driving test in order to get the data of roll, pitch, yaw moments and *x, y, z* accelerations. They will drive the same type of car on the same route. The route that has been selected is from UTeM Industrial Campus to UTeM Main Campus. Each driver will have different values of the data collected based on the way the driver the car. From the data collected from each driver that have been tested, the behavior of the driver can be analyzed. The EV3 is attached at the COG (Figure 3) tightly in order to avoid it from moving. These data are recorded based on the type of road condition, vehicle speed and the way the vehicle is controlled by the driver. During the test, a video of the trip along the way of the test is recorded for observation. The significant values of the data will be analyzed and categorized.

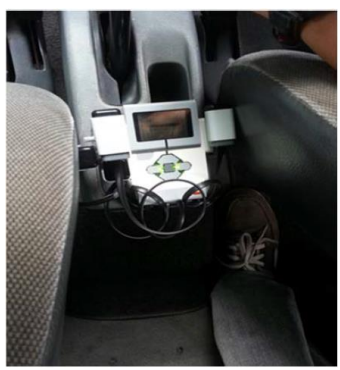

Figure 3: Location of LEGO Mindstorm EV3 [7][8][9].

Data analysis

Vehicle that makes a journey on the road tend to have a force when they are travelling through various types of road conditions such as go through a bumpy road, taking a cornering, exit of the junction and also when accelerating and decelerating. Figure 4 shows the vehicle motion from a vehicle. The force that the vehicle will be having is vibration or acceleration x, y and z axis and moments that are roll, pitch and yaw moments.

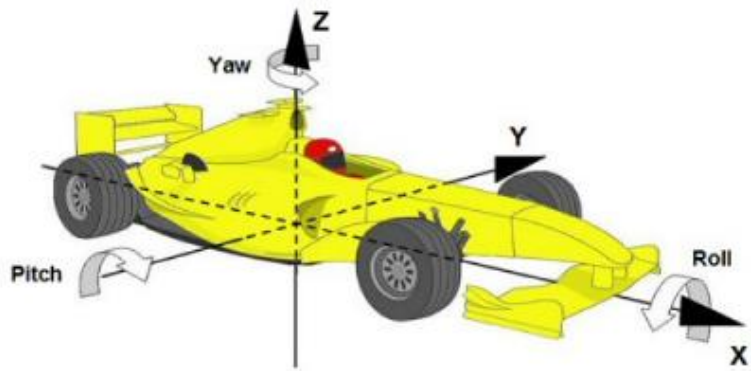

Figure 4: Vehicle Motion [14][15].

The vehicle will undergo 3 axis of rotation, which is vertical (z-acceleration), lateral (y100 acceleration) and longitudinal (z-acceleration) [14][15]. The vertical axis is an axis drawn from top to bottom, passing through the center of gravity and perpendicular to the two axes, that is when the vehicle moving up and down so the vehicle will have the value of z acceleration. Lateral axis is an axis running from left to right, passing through center of gravity. The lateral axis passes through the car from side to side. It is when the vehicle is moving right or left and the value of y-acceleration of the vehicle will appear. The longitudinal axis is an axis drawn through the body of the vehicle from front to rear in the normal direction of movement or in the direction of driver faces. It is meant that z –acceleration is the acceleration that appears when the front and rear of the vehicle is moving up or down. There are three types of moments that the vehicle will be exerted on that is roll, pitch and yaw moments [14][15]. Roll is defined as the side to side movement of a vehicle about the axis which is from the front to the rear of the vehicle that is passing through the center of gravity. It also can be said that the roll is the rotation of a car about its longitudinal x-axis. From the Figure 5, for upward movement on the right side of the vehicle, the roll is

categorized as positive (+) and for upward movement from the left of the vehicle it will be made as negative (-). Roll will be occurring in response when the vehicle taking a corner. Pitch is the movement of the front and rear of a vehicle about the axis that is from the left to right of vehicle. Pitch is taken to be positive (+) when the upward movement is at the front of a vehicle and negative (-) when the rears of the vehicle make an upward movement. The pitch will occur in response in a situation such as the acceleration and deceleration force. For the yaw, it is the left to right movement of the front of a vehicle on its vertical z-axis that axis are from the top to the bottom of a vehicle. Yaw is categorized as positive (+) when the front of vehicle makes a rotation to the right and negative (-) when the fronts of the vehicle make a rotation to the left. Yaw is happening such as due to the cornering.

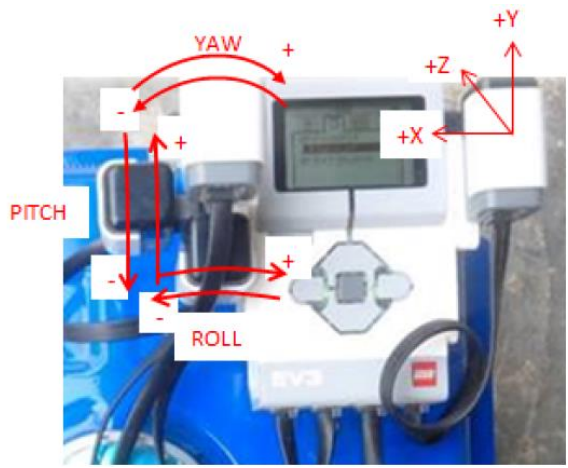

Figure 5: Movements of gyro and accelerometer sensor.

Based on the data that were collected from the driving test, the graph of roll, pitch, yaw moments and *x*, *y*, *z* acceleration against time need to be plotted. From the 10 different driver are tested, each driver will have their different values of moments and accelerations. From the, the high values of the data will be seen. Higher values indicate the aggressive the vehicle has been driven by the driver. From that, the behavior of the driver can be analyzed.

Results and discussion

During the experiment, the DAQ that are used which is the EV3 were located at the center of gravity (COG) of the vehicle that is behind the vehicle handbrake. Probably when the DAQ is attached at the surface, it is not strong enough to hold the DAQ from moving and thus the data collected will have an error. The DAQ collects the data continuously when the vehicle moving and the data with high value that is represented the aggressive behavior collected need to be identified the point or place that the data were collected in order to know in what kind of road did the vehicle experience the high force, the place that the data were collected can be identified based on the time lag from the DAQ and the video recorded but to get the specified point is not accurate. The data that are collected from the experiment has been recorded and is present in a graph according to their categories. From the graph, the data are easier to analyze because the point in which the data are in higher values compared to the others can be detected. There is 10 different series of line graph represent the drivers from the driver 1 to driver 10. The data that are being analyzed is acceleration at z-axis and the roll moment of the vehicle. This two data record the high in different when the vehicle is being experimented compare to others. So, only two type of this data is analyzed. The driving test is being conducted and 10 people are select randomly to make this test. The driving test will go through a specific road same within the all drivers which is from UTeM Technology Campus to UTeM Main Campus. The road that the drivers will pass through is as in the maps on the Figure 6. In this driving test, the vehicle will travel through many types of road and the data of accelerations and moments was recorded to see the force acting on the vehicle and the behavior of the driver controlling the vehicle.

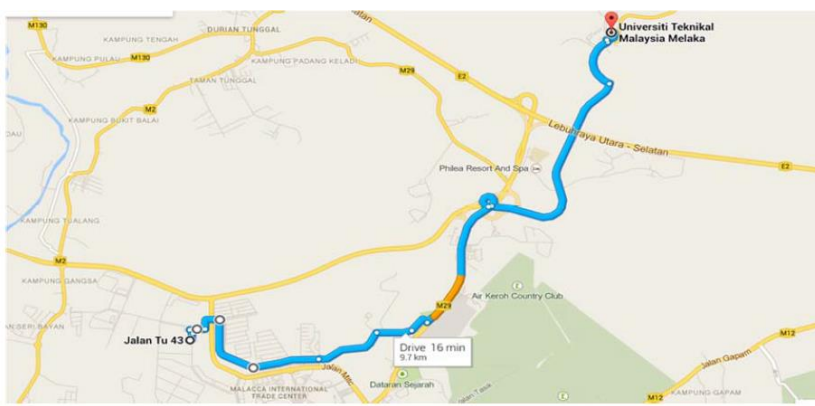

Figure 6: Route of the driving test.

Figure 7 shows the graph of the roll moment for Driver 1 to Drive 5 and Figure 8 for Driver 6 to Driver 10. Figure 10 shows the vertical acceleration from Driver 1 to Driver 5 and Figure 11 for Driver 6 to Driver 10 that have done the driving test. From the graph, the behavior of the driver can be classified based on the values that are shown. The time at certain point also can be determined from the graph to locate the location of the vehicle when the driver has any behavior that need to analyze. The graph that is at the point high from others can be classified as the driver is in the aggressive behavior state. The data considered in this experiment are vertical acceleration and roll moment because from the experiment, the path travelled by the drivers mostly has a bumpy road and corners.

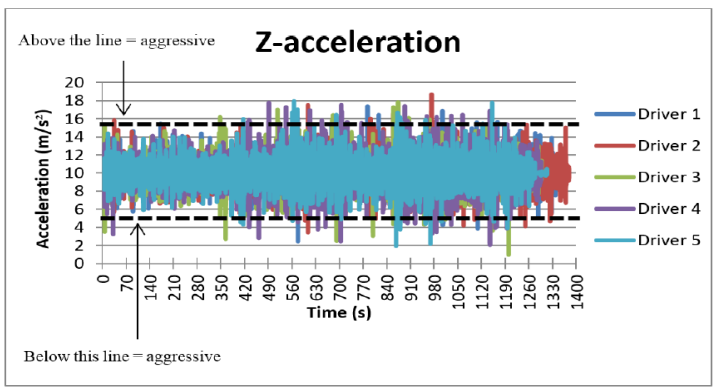

Figure 7: Driver 1 to Driver 5 vertical acceleration graph.

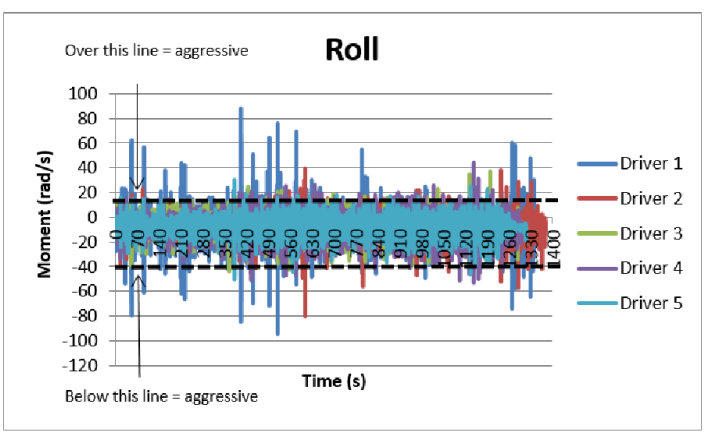

Figure 8: Driver 6 to Driver 10 roll graph.

Table 1 shows the vertical acceleration and roll moments three highest points for Driver 1 to Driver 10 with their time. From the table, the 3 highest data from each driver's Roll and Vertical acceleration values, the graph have been plotted as in Figure 9 for the Roll and Figure 10 for the Vertical acceleration. The location where the data were recorded a highest point for each driver also has been detected as in Figure 11 for the Roll and Figure 12 for the Vertical acceleration. For Driver 1, the highest value is at the point which the time is 401.73 sec that is when the vehicle is taking a corner. The highest value recorded is 87 rad/s with the speed of 52 km/h. As been analyzed, the roll moments are high when the driver is taking a corner and enter a junction. For the Z-accelerations, the highest value recorded at time 577.98 with the value of 7.51 m/s2 and the speed of 70 km/h. Data Z-acceleration record the high data when the vehicle passing through bumpy roads.

Driver 2 behavior as can be seen at table below that the highest roll moments data is at the time 607.23 sec with the value 70 rad/s and the speed 49 km/h. This is when the driver is taking a corner. For the Z-acceleration, the Driver 2 is recorded the high Z-acceleration at the time 607.15 sec with 7.49 m/s2 and the speed is 49 km/h. Driver 3 highest roll moments recorded at the time of 364.03 sec with the value 34 rad/s and the speed is 43 km/h. For the Z-acceleration, the highest point located at the time 691.84 sec with the value of 7.41 m/s2 and the speed is 67 km/h. The data record the highest values on the bumpy road. 4 highest recorded value for the roll moments is at the time of 433.85 sec with the value of 41 rad/s and the speed of 53 km/h. The driver can be said that has been control the r nicely. The driver 4 shows the high in Z-acceleration values is recorded at the time 491.58 sec with the value 7.64 m/s2 62 km/h.

The roll moments for the Driver 5 highest values recorded at time 381.30 sec with the value of 40 rad/s and the speed is 50 km/s. It is not a high value compare to others. For the Z202 acceleration, the data record the high value at time 565.80 sec with the value of 7.89 m/s2 and the speed of 79 km/h. The Z-acceleration pattern is also almost the same with the other. The driver can be said that he has a good behavior of driving.

Driver 6 roll moments are low compared to. The roll moment is record the high values at the time 539.54 sec with the value of 55 rad/s and the speed of 51 km/h. So the driver 6 is at aggressive behavior at time 539.54 sec when taking a corner. For the Z-acceleration, driver 6 record the high value at time 370.10 sec with the value of 8.36 m/s2 and the speed is 52 km/h. The values of Z-acceleration record the high values when the vehicle travels through bumpy roads.

Driver 7 roll moments highest point is located at time 413.72 sec with the value of 88 rad/s and the speed is 53 km/h. The other high points are recorded the high values compare to others. For the Z-acceleration for the

driver 7, the highest point at time 628.70 with value of 7.84 m/s2 71 km/h. At this point, the drivers always state the high in values because it has a bumpy road there

The roll moments of the Driver 8 highest value locate at time 598.09 sec with the value 48 rad/s and the speed is 56 km/h. This is when the vehicle taking a corner. The Z218 acceleration of the Driver 8 highest point locates at time 619.91 sec with a value of 8.87 m/s2 and the speed is 68 km/h. The value of the driver 8 is can be said that is high.

Driver 9 recorded high value of roll moment at time 450.12 sec with the value of 55 rad/s and the speed is 47 km/h. For the Z-acceleration, the highest values are recorded at time 581.67 sec with a value of 5.98 m/s2 and the speed is 70 km/h. Compare to other drivers, the value is not as high as other so the driver 9 also not a very aggressive driver.

Driver 10 record the high value of roll moment at time 433.35 with value of 45 rad/s and the speed is 45 km/h. The value is not so high and the driver is not driving with very aggressive behavior when taking a corner. Z-acceleration of the Driver 10 is high at time 556.93 with the value of 7.85 m/s2 and the speed of 63 km/h. The values are slightly higher and the driver probably driving with high speed at this point which has had a bumpy road.

From the 10 driver that have made the experiment, it can be analyze that the behavior of the driver depends on how the driver control the vehicle based on type of road. If the driver is aggressive, he will drive with high speed at the not suitable type of road and it will record high values of Roll and Vertical acceleration.

Table 1: Highest 3 values of roll and vertical acceleration for Driver 1 to Driver 10.

Driver	**Roll (rad/s)**	**Time(s)**	**Z-acceleration (m/s^2)**	**Time(s)**
1	69	50.09	5.44	171.80
	97	401.73	5.04	519.04
	85	519.53	7.01	577.98
2	32	86.48	5.83	34.70
	35	395.66	5.24	408.90
	70	607.23	7.49	607.15
3	34	364.03	7.26	363.40
	35	424.73	6.81	517.60
	33	555.07	7.40	691.84
4	41	433.85	6.72	31.38
	35	543.99	7.64	491.58
	36	637.10	7.26	705.50

5	40	381.30	5.93	415.70
	34	567.14	7.89	565.80
	25	691.13	6.27	691.32
6	30	430.90	5.15	76.92
	55	539.54	8.86	370.10
	41	634.13	6.56	620.84
7	62	155.38	6.46	346.80
	88	413.72	6.81	533.50
	53	545.33	8.6	642.42
8	32	185.13	6.22	467.46
	30	467.01	8.87	619.91
	48	598.09	7.54	668.20
9	30	388.97	4.66	184.07
	55	450.12	5.44	378.80
	52	689.56	5.98	581.67
10	29	344.94	6.42	214.25
	45	433.35	6.56	362.42
	34	689.74	6.28	556.93

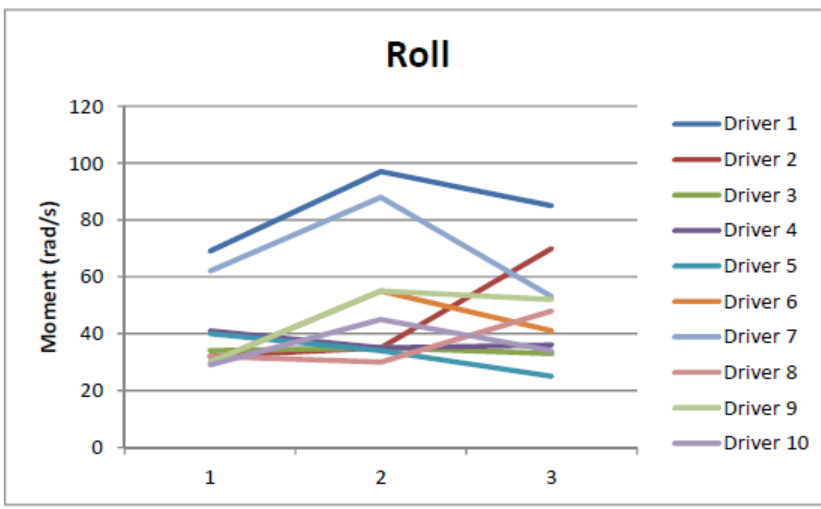

Figure 9: Graph of highest roll for Driver 1 to Driver 10.

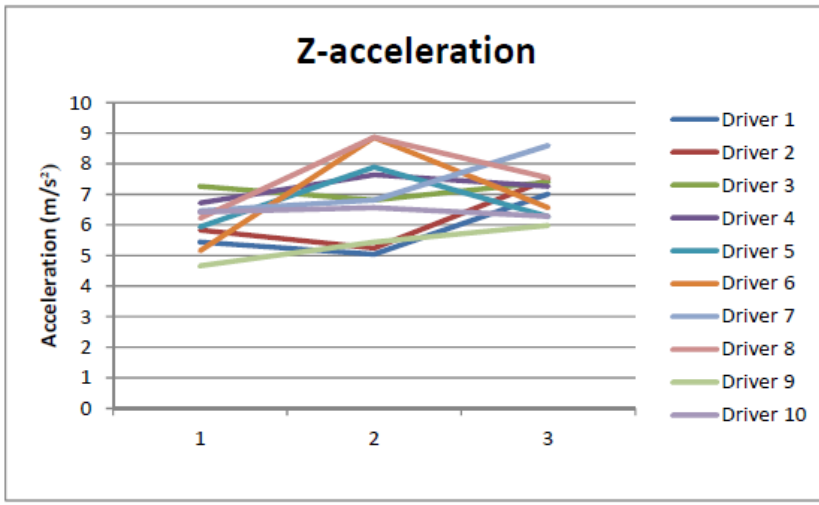

Figure 10: Graph of highest vertical acceleration for Driver 1 to Driver 10.

Figure 11: Location of the roll highest point for Driver 1 to Driver 10.

Figure 12: Location of the vertical acceleration highest point for Driver 1 to Driver 10

A vehicle with a good suspension system can reduce the accelerations and moments of the vehicle. Thus the behavior of the driver will be determined accurately only if the vehicle experience the high force applied by the driver that was an aggressive behavior.

The moments roll, pitch, yaw and *x, y, z* accelerations are depending on the movement of the vehicle. If the vehicle experience a high lateral force, the pitch moments and *y* accelerations records the high values of data. The roll moments and *x* acceleration depend on the longitudinal movement of the vehicle and the vertical movement effect the yaw and *z* accelerations. So, in which of the vehicle movement occur, the data were recorded with different range of data depends on how the vehicle is driven.

The road travel has the biggest influence on the driving behavior of the driver. It has a many type of road travel by the driver when doing the experiment such as corner, bumper, junction and uneven road. It depends on how the driver control the car when travel through this type of road. If the driver drives through the road with a suitable speed it can prevent the vehicle from experience a high force and make the driver to be an aggressive driver.

The driver that is making the experiment is selected randomly from the university drivers only. The driver is made an effect on the behavior as they are the one who controls the vehicle. As the driver is from the one who has a good background on driving and have much experience as the driver at a long time. So, this type of driver can manage to control the vehicle properly compare to the one who rarely drive

Conclusion

From the experiment that has been done, it can be concluded that the force acting on the car represents the behavior of the driver. The driver which has high experience in driving has more skill when driving and manage to control the vehicle with good manner to prevent the car experience a high force. Vehicle system such as the suspension system has influenced the vehicle performance in isolating the accelerations and moments acting on the vehicle. A good suspension system will reduce the high accelerations and moments acting on the vehicle and will give the driver and the passengers more comfortable when driving. This experiment also can be done again with the different type of vehicle and different objective to further the study to prevent the bad behavior of the driver acting on the car that can lead a danger to the driver, passenger and also to other people.

Acknowledgements

The authors gratefully acknowledged the Advanced Vehicle Technology (AcTiVe) research group of Centre for Advanced Research on Energy (CARe), the financial support from Universiti Teknikal Malaysia Melaka and The ministry of Education, Malaysia under Short Research Grant, Grant no. PJP/2014/FKM (10A)/S01330 and Fundamental Research Grant Scheme (FRGS), grant no.: FRGS/2013/FKM/TK06/02/2/F00165.

References

[1] Harun, M. H., W. Abdullah, W. M. Z., Jamaluddin, H. and Hudha, K. "Analysis of Primary and Secondary Lateral Suspension System of Railway Vehicle." *Journal of Mechanical Engineering* (JMechE) 11.2 (2014): 19-40.

[2] Lárusdóttir, E. B., and Ulfarsson, G. F. "Effect of Driving Behavior and Vehicle Characteristics on Energy Consumption of Road Vehicles Running on Alternative Energy Sources." *International Journal of Sustainable Transportation* 9.8 (2015): 592-601.

[3] Munehiro, K., Takada, T., Kageyama, H., Takahashi, N., & Ishida, T. "Judgment of Appropriate Speed and Driving Behavior with Different Road Surface Conditions in Curve Sections." *Transportation Research Board 93rd Annual Meeting*. No. 14-1078 (2014).

[4] Hallmark, S. L., Tyner, S., Oneyear, N., Carney, C., & McGehee, D. "Evaluation of Driving Behavior on Rural 2-Lane Curves using the SHRP 2 Naturalistic Driving Study Data." *Journal of safety research* 54 (2015): 17-e1.

[5] Taubman-Ben-Ari, O., Musicant, O., Lotan, T., & Farah, H. "The

Contribution of Parents' Driving Behavior, Family Climate for Road Safety, and Parent-Targeted Intervention to Young Male Driving Behavior." *Accident Analysis & Prevention* 72 (2014): 296-301.

[6] Classen, S., Wang, Y., Winter, S. M., Velozo, C. A., Lanford, D. N., & Bédard, M. "Concurrent Criterion Validity of the Safe Driving Behavior Measure: A Predictor of On-Road Driving Outcomes." *American journal of occupational therapy* 67.1 (2013): 108-116.

[7] Abdullah, M. A., Jamil, J. F. and Salim, M. A. "Dynamic Performances Analysis of a Real Vehicle Driving." *IOP Conference Series: Materials Science and Engineering.* 100 (2015): 012017. doi:10.1088/1757-899X/100/1/012018.

[8] Abdullah, M. A., Salim, M. A., Mohammad Nasir, M. Z., Sudin, M. N. and Ramli, F. R. "Dynamics Performances of Malaysian Passenger Vehicle. " *ARPN Journal of Engineering and Applied Sciences.* 10.17 (2015): 7759-7763. ISSN 1819-6608.

[9] Abdullah, M. A. and Abdul Rahim, M. A. H. "Driving Behaviour Analysis of Young Vehicle Drivers." *Proceedings of Mechanical Engineering Research Day 2016* (2016): 19-20.

[10] Abdullah, M. A., Ramli, F. R. and Lim, C. S. "Railway Dynamics Analysis Using Lego Mindstorms." *Applied Mechanics and Materials*. Trans Tech Publications. Vol. 465-466. (2014): 13-17. doi:10.4028/www.scientific.net/AMM.465-466.13

[11] Abdullah, M. A., Jamil, J. F., Ismail, N., Mohammad Nasir, M. Z., and Hassan, M. Z. "Formula Varsity Race Car - Roll Dynamic Analysis." *Proceedings of Mechanical Engineering Research Day 2015* (2015): 23-24.

[12] Abdullah, M. A., Azan, M. A., Ramli, F. R., and Mohamed Nor, M. K. "Autonomous Vehicle Convoy using Lego Mindstorms." *Proceedings of Mechanical Engineering Research Day 2015* (2015): 27-28.

[13] Abdullah, M. A., Romeli, M. A., Ramli, F. R., and Mohamed Nor, M. K. "Driving Assistance System - Automatic Parking Maneuver using Lego Mindstorms." *Proceedings of Mechanical Engineering Research Day 2015* (2015): 25-26.

[14] Abdullah, M. A., Jamil, J. F., Mat Yamin, A. K., Mat Nuri, N. R. And Hassan, M. Z., Vehicle Dynamics, *Teaching and Learning Series, Faculty of Mechanical Engineering*, Module 10, Penerbit Universiti, Universiti Teknikal Malaysia Melaka (2015).

[15] Abdullah, M. A., Jamil, J. F., Mohan, A. E., Mat Yamin, A. K. And Tamaldin, N., Vehicle Dynamics – Analysis & Experimentation, *Teaching and Learning Series, Faculty of Mechanical Engineering*, Module 13, Penerbit Universiti, Universiti Teknikal Malaysia Melaka (2016).