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Experimental study of the vehicle dynamics behavior during lane changing in different speeds

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Abstract. During lane changing, the speed of the vehicle is related to the stability of the vehicle. If the driver changes the lane at a high speed, the vehicle will lose its stability and it can increase the possibility of an accident. In this study, the experiment has been developed to analyse how the speed of the vehicle can affect the vehicle dynamics behavior. To achieve this objective, the UMP Test Car which employed with global positioning system (GPS), steering torque and angle sensor, displacement sensor and gyro sensor is used in the experiment. The experiment is run at the UMP test track and the track has 2 lanes which can allows the vehicle to change the position from the left to the right. In the experiment, when the GPS monitor shows 30 km/h, the driver will maintain the speed and start to turn the steering just after the test car reaches to the first skittle. Then, the driver will turn again the steering when the test car reaches to the second skittle. This method is repeated two times and the same methods is used for the speed 50 km/h. The data from the sensors is recorded in the Dewetron software and the graph is plotted. From the experimental results, the steering angle, steering torque, yaw rate and displacement for the speed 30 km/h is smaller than 50 km/h. It means that during lane changing, the speed 30 km/h is more stable compared with 50 km/h.

1. Introduction

In general, ground vehicle can be divided into two categories; track vehicle such as train and untrack vehicle such as cars [1]. For untrack vehicle, it can move in various direction on the ground according to the steering angle given from the driver. The steering angle is not just change the direction of the vehicle, it also can affect the stability of the vehicle[2]. To analyse the stability of the vehicle, the vehicle dynamics equation of motion is used and the vehicle is considered to have six degree of freedom; vertical motion in the z -direction, lateral motion in the y -direction, longitudinal motion in the x -direction, rolling motion in the x -axis, pitching motion around the y -axis, and yawing motion around the z -axis [3]. By analysing of these motion, the control system to improve the stability of the vehicle can be developed.

The other aspects need to be considered during lane changing is the road traffic. Xiang Li et al have studied the optimal traffic control during lane changing. The effect of the lane changing to the traffic efficiency, safety and environmental impact are considered. Their findings provide guidance for the traffic management and important for the researcher to achieve high traffic efficiency [4].

Impact of in-vehicle navigation information on lane-change behavior has been studied by Meinging Yun et al. The experiment is done in the simulator and the road is in the urban expressway. Six indicators which are merging gap, position, delay, steering angle, deceleration, and safe distance of lane changing are analysed to determine the lane changing characteristics. In the experiment, the



traffic flow density is taken into account and the result shows that the proposed navigation had positive impact under medium to high traffic density [5].

A dynamic automated lane changing has been developed by Yugong Luo et al. In their study, the vehicle-to-vehicle communication is used to develop the automated lane changing. The trajectory planning in their model will be the reference trajectory because the trajectory planning satisfying the safety, ride comfort and road traffic [6]. The lane changing of the autonomous vehicle also has been studied by Maksat Atagoziyev et al. They have developed an algorithm for the vehicle to change the lane in a short period of time. In the algorithm, they have considered the trajectory of all vehicles and also considered the traffic safety. Their algorithm has been applied in the various situation to ensure the functionality [7].

Lane changes prediction based on adaptive fuzzy neural network (AFNN) has been developed by Jinjun Tang et al. By using the information from the vehicle sensors, the AFNN can predict the steering angle. The experiment is developed in the simulator and the experimental result shows that the proposed method is able to follow the desired steering angle [8].

In terms of vehicle stability during lane changing, the yaw rate of the vehicle can be an indicator to measure either the vehicle is in a stable condition or not. Over the past years, there are many studies on yaw moment control. M. Heerwan et al have developed the direct yaw moment control using tire steer angle to improve the steer performance in the disturbance condition. The control strategy that they have used in their model is optimal control. In the analysis, the wind disturbance is added at the lateral axis and the result shows that by using direct yaw moment control, it can improve the steer performance of the vehicle [9].

To improve the stability of the vehicle, the vehicle must have the optimum yaw rate and this optimum yaw rate can be achieved if the control system of the vehicle can know the error between the desired and actual yaw rate. Dong-Hyung et al have developed an adaptive direct yaw-moment control method for electric vehicle based on identification yaw rate model. The identification yaw-moment control can minimize the yaw rate errors and finally the vehicle will follow the desired vehicle dynamic model [10]. Based on the advantages of the in-wheel motor at the electric vehicle (EV), which is electric motor can be controlled independently, Bingtao et al have developed MPC-based yaw stability control in in-wheel motored EV via active front steering and motor torque distribution. From their study, it is approved that yaw rate and vehicle stability can be improved by controlling both the steer angle and individual torque at each tire [11].

Although many studies on vehicle stability during lane changing, the analysis of the vehicle dynamics behavior at the different speed is very crucial because it can be a reference for the researcher to develop their control system. The objective of this study is to analyse the vehicle dynamics behavior during lane changing at the different speed. UMP test car that equipped with the high technology sensors is used as the experimental vehicle model. The track that has been used in the experiment is inside the UMP. Considering the vehicle is changing the lane in the UMP road, two types of the speed which is 30 km/h and 50 km/h are used in the experiment. The experimental result shows that the steering torque, steering angle, yaw rate and displacement for the 30 km/h is smaller than 50 km/h. From this results, it is understood that at a higher speed, the vehicle exhibits more violent behavior.

2. Experimental Vehicle Model

Figure 1 shows the UMP Test Car that has been used in the experimental and the specification of this vehicle is shown in Table 1.



Figure 1. Test car UMP.

Table 1. Specification of the experimental vehicle model.

Drive type	Front wheel drive
Gearbox	4-speed automatic
Front brake system	Ventilated Disc
Rear brake system	Drum
Tire Size	195/60/R15
Length	447.8 cm
Width	172.5 cm
Height	143.8 cm
Front/rear track	147.6/147.1 cm
Wheelbase	260.1 cm
Unladed weight	1195 kg

The steering angle and torque sensors, gyro sensor and displacement sensor are shown in the Fig.2,3 and 4. The function of the steering angle and torque sensors are to measure the steering angle and torque when the driver turn the steering wheel. If the value of the steering angle and torque are high, means that the driver turn the steering wheel very fast. During lane changing, the load will transfer from the one position to another position. This will affect the displacement at the upper arm and lower arm. In this experiment, the displacement sensor is used to measure the displacement from the upper arm to the lower arm. Lane changing also can affect the yaw rate of the vehicle. The gyro sensor that located at the center of the vehicle is used to measure the yaw rate of the vehicle. If the value of yaw rate is high, means that the changes of the angle per second is very fast and it can contribute to the instability of the vehicle.



Figure 2. Steering Angle and torque sensors.



Figure 3. Displacement Sensor.



Figure 4. Gyro sensor.

3. Experimental Method

The experiment has been conducted in the UMP and the route for the experiment is shown in Fig 2. In the experiment, the driver will change the lane from the left side to the right side and then turn back to the left side as shown in the Fig.6. Before start the experiment, all the sensors are calibrated in the Dewetron software. Dewetron software is the data acquisition setup in the experimental vehicle model. After the sensors are calibrated, the driver will start the engine and drive the vehicle to the experiment area. When the GPS monitor shows 30 km/h and the vehicle approach to the first skittle, the driver will turn the steering to the right side. Then, when the vehicle is approach to the second skittle, the driver will turn the steering to the left side. All the data from the sensors are recorded in the Dewetron software and the results are plotted in the graph. This method is repeated for the speed 50 km/h and each experiment is repeated three times.

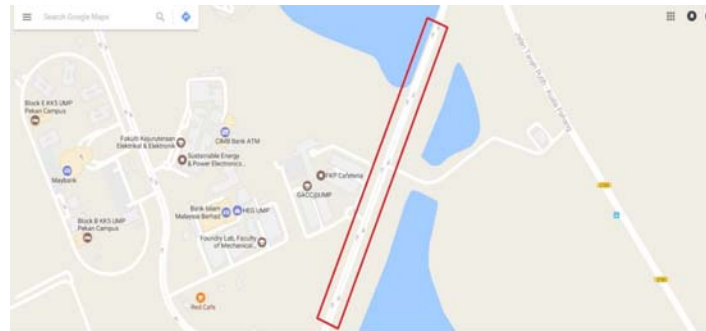


Figure 5. Route for the experiment.

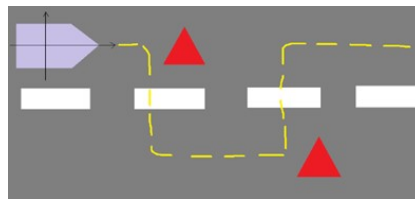


Figure 6. Lane changing of the vehicle in the experiment.

4. Results and Discussion

4.1 Relation between steering angles with the vehicle speed

Figure 7 shows the graph of the comparison of effect on steer angle with the different vehicle speed. As seen in the graphs above the patterns of the data are quite similar because the test vehicle is moving with the same pattern which is changing lanes from left – right – left. The comparison is using the data of the 30km/h and 50km/h which are the lowest and highest speed respectively. From the data it can be observed that the graphs are similar but the base value of steer angle is different. 50km/h has the smallest base while 30km/h has the largest base. The change in steer angle in 50km/h is more abrupt than the 30km/h as seen in the graph. Thus, we can conclude that, the faster the speed of vehicle, the faster the time it takes to lane change or to navigate around road obstacles.

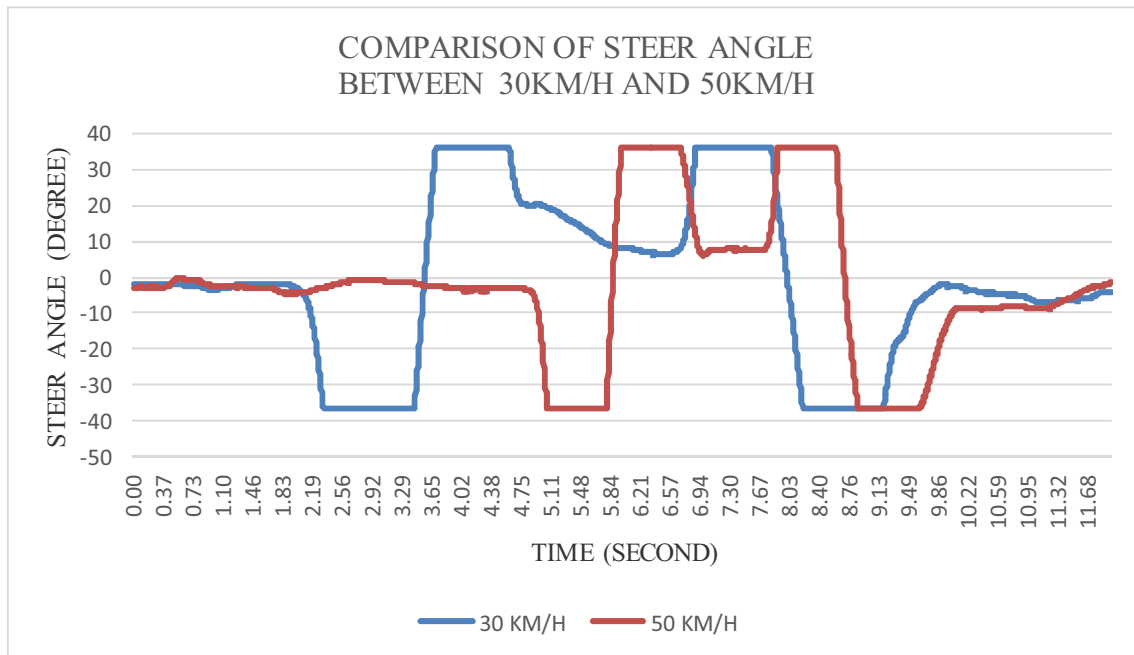


Figure 7. Steer Angle at 30km/h and 50 km/h.

4.2 Relation between steering torques with the vehicle speed

Figure 8 shows the graph of the comparison of steering torque with different vehicle speed. From this data, it can be seen that the pattern is quite similar between those two speeds. Even the peaks of the graphs are more or less the same value. The steering torque at the different speed is similar because at a high speed, a small torque at the steering wheel can increase the steering angle immediately. In contrast, at the small speed, the driver need to push the steering wheel harder to steer the steering wheel.

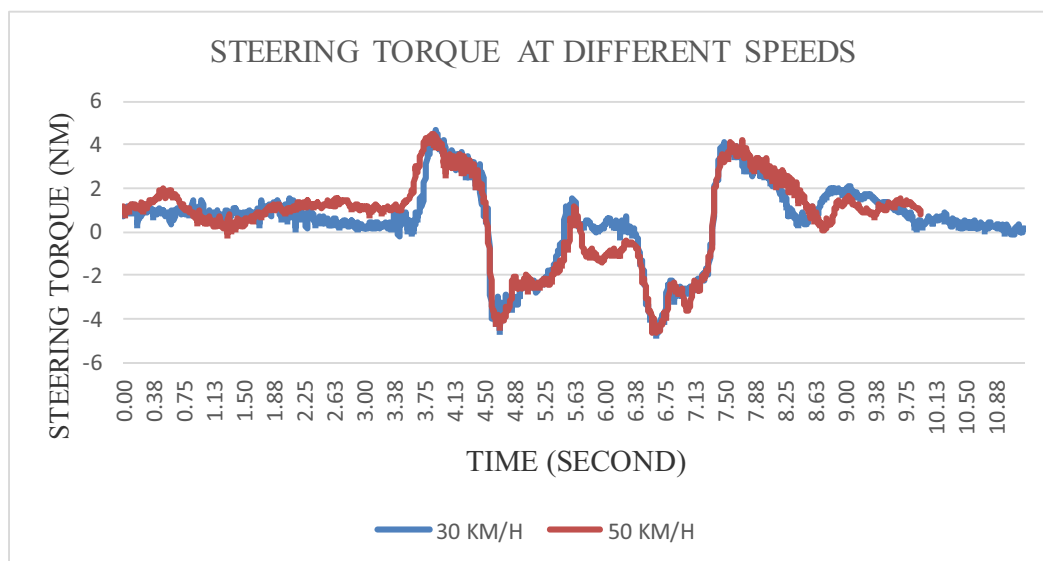


Figure 8. Steering Torque at 30 km/h and 50 km/h.

4.3 Relation between yaw angles with the vehicle speed

Figure 9 shows the graph of comparison on the effect to yaw angle at different speed of the vehicle. Based on the Fig.7 and Fig.8, the data curves are relatively similar in shape and pattern. This similarity

are due to the fact that the test vehicle is moving at the same pattern which is changing lane from left – right – left. From the data of 30km/h, and 50km/h we can observe that the graphs are similar in shape but the peak amplitude of yaw angle is different. At 50km/h has the highest peak with the value of 45.34° while 30km/h has the lowest peak with the value of 39.02° . A faster moving vehicle will have to turn more quickly than a slower moving vehicle in order to clear the same distance when lane

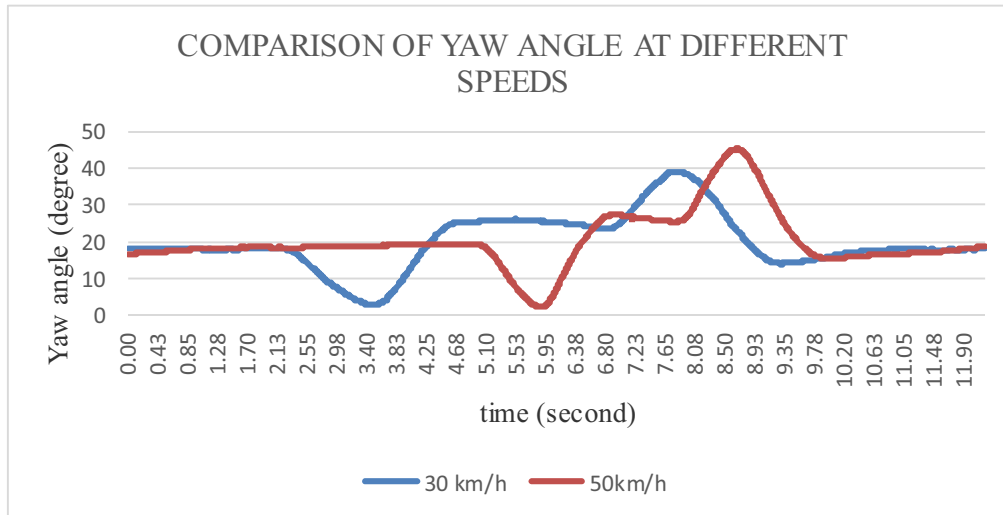


Figure 9. Yaw angle at 30 km/h and 50 km/h.

Changing or avoiding obstacles on the road. A faster moving car carry bigger inertia, and will produce larger yaw angle (γ). Thus, we can determine that, the faster the speed of vehicle, the bigger the yaw angle produced.

4.4 Relation between displacements with the vehicle speed

Figures 10 and 11 shows the displacement sensor data for 30km/h and 50km/h respectively. When the graphs indicate a positive peak value, it means that the specific sensor is going in a positive vertical direction. Vice versa, if negative value is recorded this implies that the sensor is going negative vertical displacement. From Fig 10 and Fig 11, the higher speed records a greater peak value compared to the slower speed. This can be attributed to the fact that the car will tend to roll more at higher speed when making a lane change or turning.

In a turn, the car's tires are generating mechanical grip which is pulling the car inside the turn (centripetal force), the reaction to this force (i.e. the centrifugal force) pushes the car outside the turn. This centrifugal force is acting about the car's center of mass. Since the center of mass is always above the point of the car touching the ground, there is a turning force produced (the rolling moment) about the ground contact point. This becomes the pivot point. Higher the center of mass, more the rolling moment. This turning force causes the car to roll. This forces is resisted by the suspension.

Body roll is not desirable. Rolling causes the weight of the car to shift to the outside of the turn. Thus there is less downward force pushing down on the inside wheels. Thus the inside wheels produce less grip. This affects the car's handling and can cause the car to understeer. If the rolling moment is too high (too much speed or too tight a turn) then the whole car can roll-over and crash. This is because the rolling moment exceeded the resisting force of the suspension springs of the outer wheels.

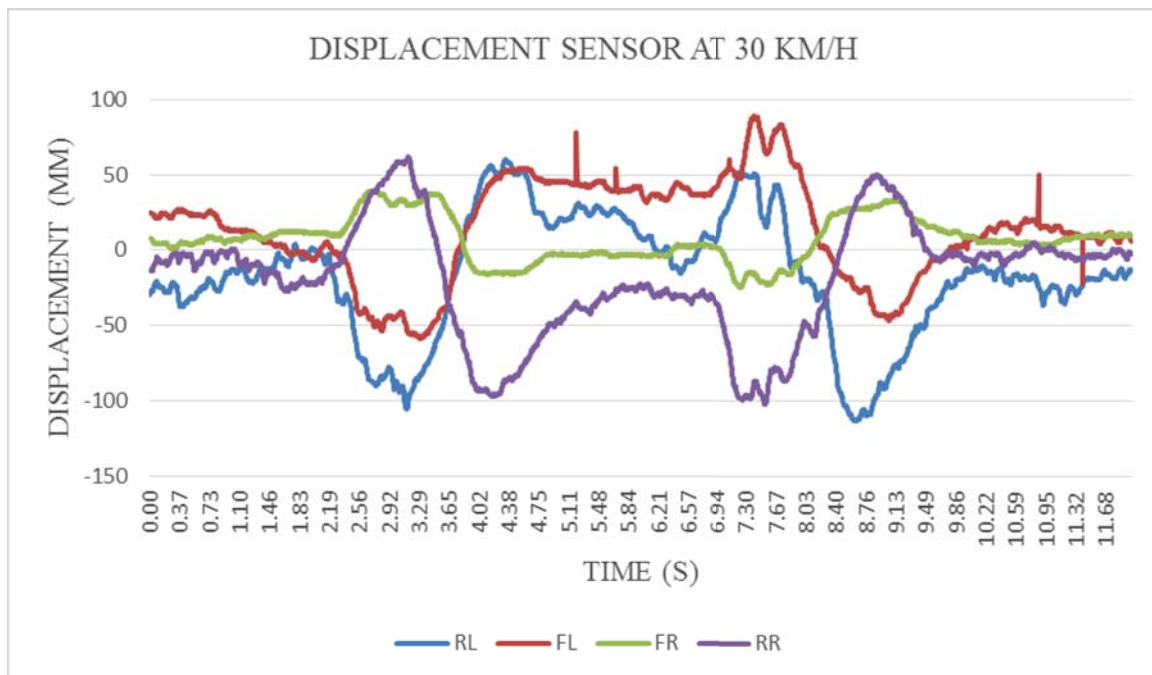


Figure 10. Displacement at each tire at 30 km/h.

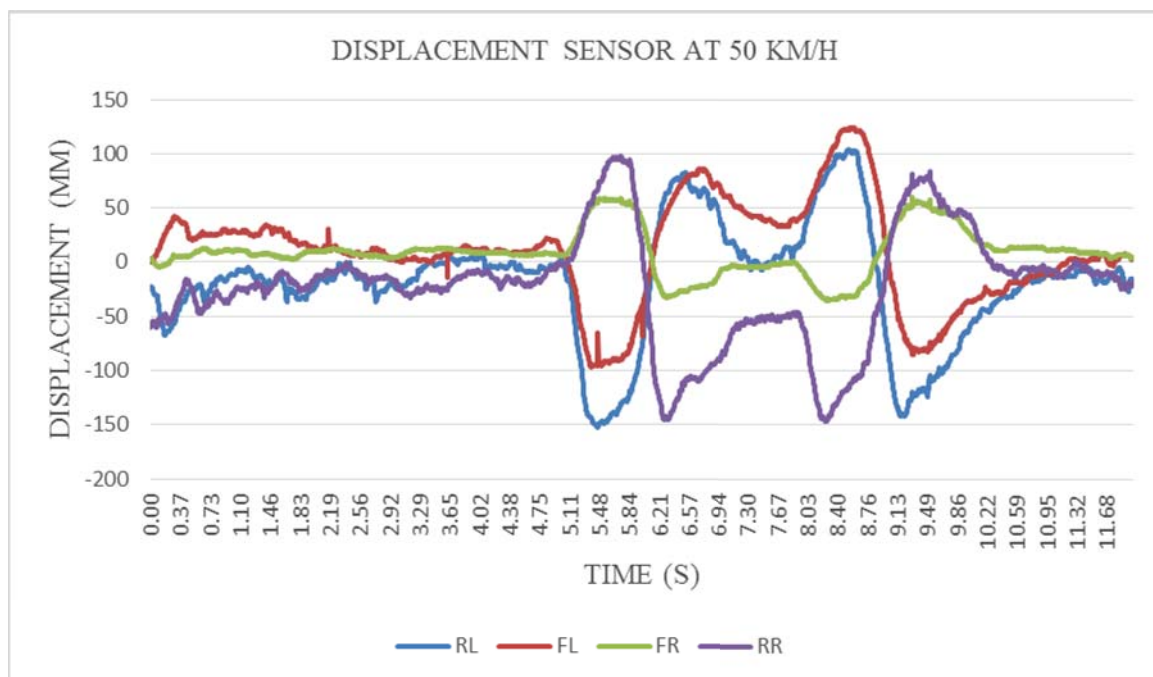


Figure 11. Displacement at each tire at 50 km/h.

5. Conclusions

From the experiment, the vehicle behavior during lane changing in the different vehicle speed is obtained. A vehicle moving with faster speed will produce higher yaw angle when lane changing. While if the vehicle is moving at a slower speed, the steering angle base will be big when changing the lane. If the vehicle is moving with a higher speed, a more abrupt change of steer angle can be seen from the graph resulting in a smaller base area of steer angle.

It can be concluded that if changing lane at a faster speed is quite hazardous as the yaw produced is significantly higher. The abrupt change in steer angle also can be dangerous as the tires might

experience slipping which will result in a loss of control in a car. For a front wheel drive such as the test vehicle, the vehicle might suffer from understeer.

Changing lane at slower speed, will have a smaller yaw angle and larger base of steer angle. A smaller yaw angle can prevent the vehicle from spinning or rolling too much and goes out of control. A larger base of steer angle can give us more gripping on tire as the tire changes direction gradually in the same amount of time it takes to change lane. The results in the experiment support the objective to analyse the vehicle dynamics behavior during lane changing at different speed. From the results, researcher can consider the stability factor in order to develop the lane changing control system.

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