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Research on Rear Wheel Steering for a Small Electric Vehicle (Effect of Torque Balance)

by

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Abstract

Problems regarding fuel consumption and ride comfort of a small electric vehicles have been gaining concern in the recent years. Furthermore, the environmental impact of the petroleum-based transportation infrastructure, along with the peak oil, have led to renewed interest in an electric transportation infrastructure. However, electric vehicles on the market right now have a problem in that the angle of cornering is not small enough for them to be fully used in a narrow road and therefore there is some difficulty in maneuvering the vehicles. The object of this research is support of Rear Wheel Steering Small Electric Vehicle (RWSSEV). The theory for this research is that the difference in torque from both rear wheels is used to control the steering and thus give more freedom for the maneuvering of the vehicle. This will improve the cornering of the vehicle and has the advantage of moving it easily in a small space. This report explains about the effect of the driving torque balance of left and right tires on the motion characteristics of the RWSSEV by using simulations and model experiments. In this research, two types of simulation were done one which a different amount of torque input was given in the same direction of the turn, while the second simulation process used the same amount of torque input as was first given but in the opposite direction. Futhermore, the simulation results were confirmed by the model experiments.

Keywords: Rear wheel steering small electric vehicle (RWSSEV), Difference in torque from both rear wheels, Motion characteristic, Torque balance

1. Introduction

Electric vehicles have been long promoted as a promising alternative to the current fossil fuel-based mobility system. Greenhouse gas and air pollutants emissions, rising fuel costs and supply uncertainties have been contributed to the proposal of changing our mobility system towards electric mobility. There are two main types of electric vehicle technologies ; Battery Electric Vehicles (BEV) which are fully-electric vehicles with rechargeable batteries and no gasoline engine while Plug-in Hybrid Electric Vehicle (PHEV) which can recharge battery through both regenerative braking and "plugging in" to an external source of electrical power.

The fundamental of the driving method for electric vehicle can be separate into two types which are one motor system and in-wheel motor system. The basic principle behind a vehicle equipped with in-wheel electric motor is that the internal combustion engine that is normally found under the hood is simply not necessary. It is replaced with at least two motors located in the hub of the wheels. These wheels contain not only the braking components, but also all of the functionality that was formerly performed by the engine, transmission, clutch, suspension and other related parts.

This result in the increasing usage of in-wheel motor in electric vehicle nowadays. The difficulty of handling a conventional steering system also trigger the usage of using in-wheel motor system. This will surely be an advantage for the vehicle to steer especially in narrow and small roads. Furthermore, given the fact that this research is focusing on small electric vehicle, this can give an extra advantage as the research vehicle is in small size.

In this research, the RWSSEV is equipped with in-wheel motor system at both of its rear tire. By using this

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system, we can control the driving torque on each tire of the electric vehicle indepently. The front tire will only be used as auxiliary balance for the vehicle body and thus the effect will be neglected. The main idea of this research is that, the movement of the electric vehicle is control by using the difference in torque from both tire and thus, causing it to accelerate forward or turning into a desired direction. By using this idea, we can control the movement of the vehicle freely and also it can give a bigger angle of cornering to the vehicle.

The procedures that were carried out in this research can be divided into two categories; simulation process and experiment process. As for the simulation process, two types of simulation were done which was the different amount of torque input was given in the same direction while the second simulation process was the same amount of torque input was given but with an opposite direction. The movement of the vehicle is observed through a simulation software as a result of the simulation. Meanwhile, as for the experiment process, a weight is attached at a different position of the model vehicle and the experiment was carried out to see the difference of the vehicle movement.

2. Main symbols

F : Friction force, g : Gravitational Force, I : Moment of inertia, I_T : Tire inertia, k : Parameter representing road condition, m : Body mass, R_0 : Tire radius, r : Yaw Angular Velocity at Center of Gravity, T_D : Driving Torque, T_f : Friction Torque, u : Vehicle Longitudinal speed, v : Vehicle Lateral speed, W : Drive wheel load, X : Driving force in the longitudinal direction of the vehicle body, Y : Force in lateral direction of vehicle body, β : Side slip angle, μ : Driving friction coefficient, ρ : Slip ratio, ω : Angular velocity of tire

3. Analysis

3.1 Simulation model

The simulation is done by referring to Toyota COMS. Fig.1 shows the image of the vehicle. However, in the simulation process, a slight modification is done by changing the location of rear wheel tire to the center axle of vehicle body. The modification that is done in the simulation can be seen in Fig.2 where the tire is situated at the center of the vehicle body. In doing the simulation, a conventional vehicle would have six degree of freedom; translation motion of x, y and z axis, and rotation motion around

Fig. 1 Image of Toyota COMS

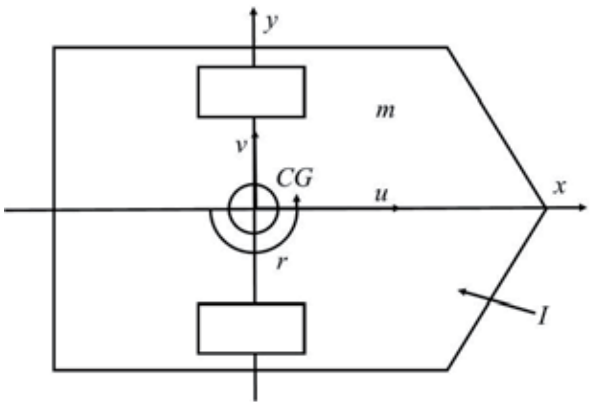

Fig. 2 Analysis model

Table 1 Parameter for analysis model

Parameter	Symbol	Value	Unit
Body Mass	m	422	kg
Tire radius	R_0	0.23	m
Tire inertia	I_T	2.53	kgm^2
Wheel Load	W	1034.5	N

the x, y and z axis. However, in this paper, the translation motion on z axis, rotation motion around the x and y axis were disregarded. Table 1 shows the parameter of the analysis model of the vehicle.

3.2 Dynamic equations

The dynamics of longitude and lateral direction, including the yaw rotation equation were calculated [1]. Longitudinal direction equation of motion is expressed as :

$$m\left(\frac{du}{dt} - vr\right) = X_l + X_r \tag{1}$$

Lateral direction equation of motion is expressed as :

$$m\left(\frac{dv}{dt} + ur\right) = Y_l + Y_r \tag{2}$$

Yaw angle equation of motion is expressed as :

$$I\,\frac{dr}{dt} = \frac{dr}{2}\,(X_r + X_l) - l_r\,(Y_r + Y_l) \tag{3}$$

3.3 Tire Characteristics

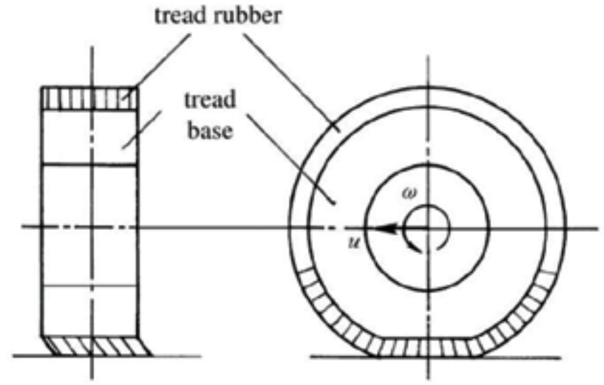

Fig. 3 Brush tire model

The forces in the dynamic equation of motion are produced from the result of friction between the tire and road surface. Figure 3 shows how the tread rubber is fitted circumferentially to the stiff rim, and the tread base is the only elastic part. This model allows elastic deformation in both the longitudinal and lateral directions. The tread rubber, similar to the previous model, is not a continuous circular body, but consists of a large number of independent springs around the tire circumference. This type of tire model is called the brush tire model. The longitude and lateral force equation can be calculated using the equations from this model [2].

However, in order to calculate the forces from brush tire model, it is important to calculate the value of side slip angle, slip ratio and friction coefficient. The equation for side slip angle for each tire can be expressed as follow [3]:

$$\beta_R = tan^{-1}\left(\frac{v - rl_r}{u + \frac{d_r r}{2}}\right) \tag{11}$$

$$\beta_l = tan^{-1}\left(\frac{v - rl_r}{u - \frac{d_r r}{2}}\right) \tag{12}$$

Tire vehicle speed and tire angular velocity is needed in order to calculate the side slip angle. Tire vehicle speed can be obtained from the equation of motion of vehicle body (Eq. 1 & Eq. 2). Slip ratio ρ can be expressed as the traction between the road and tire surface. By using the slip ratio value, an approximation of the friction coefficient μ can be calculated. While tire angular velocity can be obtained from the angular motion of equation. The angular velocity of tire ω which specifies the angular speed (rotational speed) of an object and the axis about which the object is rotating can be expressed in Eq. (15).

$$\rho = \frac{u - R_0\omega}{R_0\omega} \tag{13}$$

$$\mu = -1.1k(e^{-35\rho} - e^{-0.35\rho}) \tag{14}$$

$$\begin{cases} k = 0.8\ (dry\ asphalt) \\ k = 0.2\ (icy\ road) \end{cases}$$

$$\frac{d\omega}{dt} = \frac{T_D - T_f}{I_T} \tag{15}$$

3.4 Analysis Method

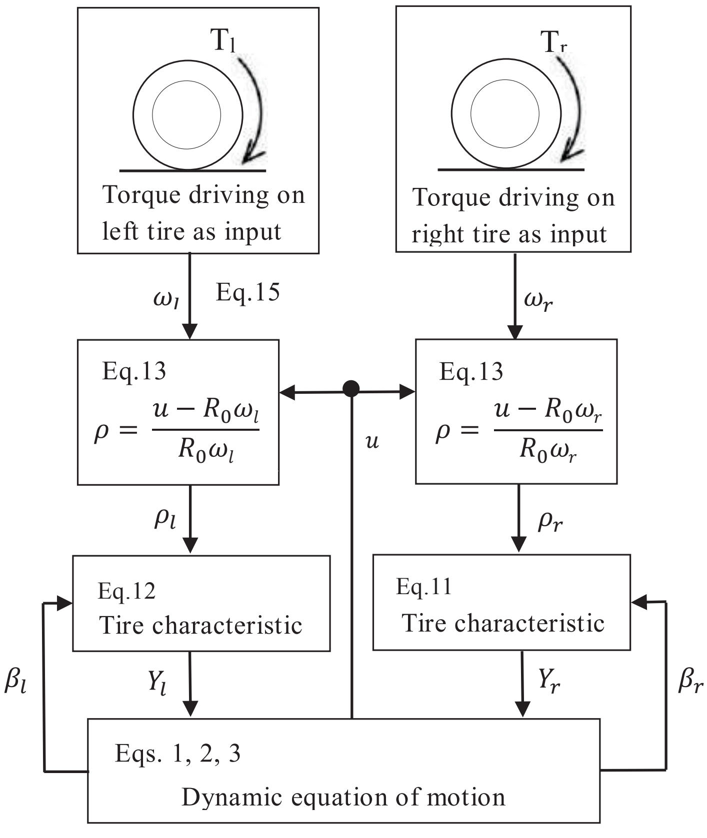

Fig. 4 Simulation flow chart

The basic principle for the simulation method is that torque driving is given as the simulation input for both left and right tires. Based from Fig.4 simulation flow chart, a certain amount of torque will be given to both tire as input. Angular velocity of tire ω and slip ratio ρ were calculated from the torque given using Eq. (15) and Eq. (13) respectively. By using the slip ratio value, an approximation of the friction coefficient μ can be calculated. At the same time, the value of side slip angle β for each tire can is calculated using the Eq. (11) and Eq. (12). Then, the overall forces acting on the whole tire contact surface, in longitude X, and lateral directions Y, is calculated using the value of friction coefficient μ, slip ratio ρ and side slip angle β. The value of longitude X, and lateral directions Y, is then be used to calculate longitudinal direction equation of motion u, lateral motion equation v, and yaw angle equation of motion r.

In this research, the simulation process is divided into 2 cases. The first case is both of the driving torque inputs are in the same direction with different amount of torque while the second case is the driving torque input is in different direction but with the same amount of torque.

3.5 Analysis Conditions

(1) Same direction with different amount of torque input (Case 1)

The flow of the simulation is that the driving torque for both tire of the vehicle is set as input. In this simulation, the driving torque for left tire is set at 10 [Nm] while the driving torque for right tire is set at 40 [Nm]. The movement of the vehicle is then be observed.

(2) Different direction with same amount of torque input (Case 2)

The overall flow of the simulation is as same as stated in the process above. The input for the whole simulation process; which is the driving torque for left tire is set at -40 [Nm] while the driving torque for right-tire is set at 40 [Nm]. However, the equation that is used to calculate the slip ratio in this case is slightly different from previous. The movement of the vehicle is then be observed.

4. Experiment

4.1 Constructin of Model Vehicle

Fig.5 shows the model vehicle. This research is focusing on rear wheel steering vechicle, thus the front tire of the vehicle was neglected. In order to do that, a spherical ball was used as the front tire so that it would not had any effect on the vehicle movement and acted as auxiliary balance for the vehicle body.

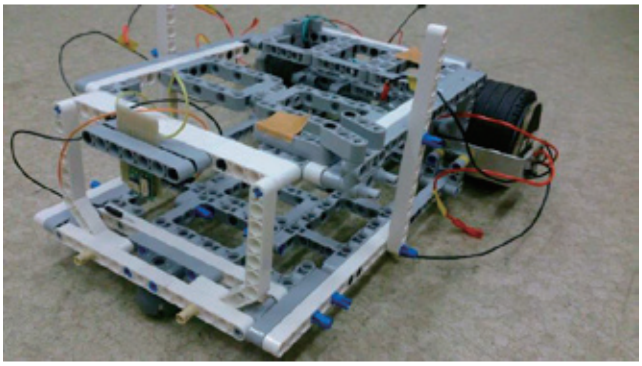

Fig. 5 Lego model vehicle

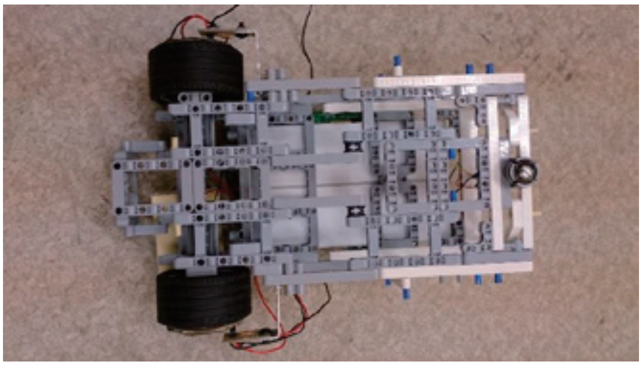

Fig. 6 Lego model vehicle (bottom view)

(1) Model vehicle dimension

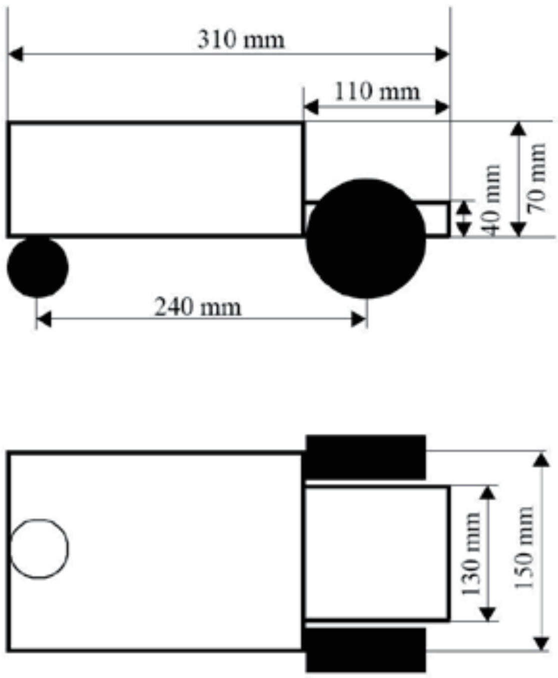

Fig. 7 Dimension of experiment model

(2) Model vehicle component

Front tire – spherical ball

Material : Steel, diameter : 17mm

Motor – Lego Power Function medium motor

Motor that were used in the experiment is lego power function medium-sized motor. The maximum torque is 40mNm (300mA). Without load, the rotation speed is around 380 rpm.

(3) Sensor

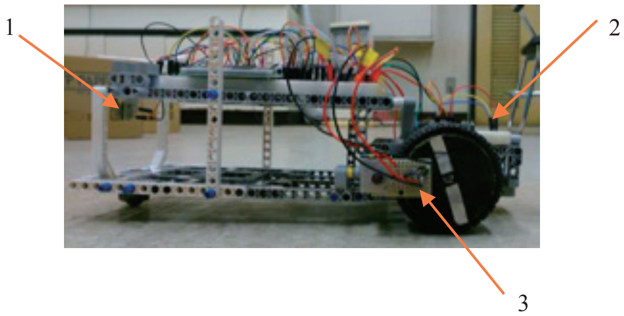

Fig. 8 Lego model vehicle (side view)

1. Piezoelectric vibration gyro module (ENC-03R)

Power-supply voltage range	2.7 ~ 5.25 V
Quiescent	1.5 V
Detection range	±300 deg/sec
Sensitivity	0.67 mV/deg/sec
Responsiveness	50 Hz

This vibration gyro sensor was used in order to measure the yaw angular velocity of the vehicle.

2. 3-axis acceleration sensor (KXR94-2050 module)

Power-supply voltage range	2.5 ~ 5.25 V
Measurement range	±2 g
Quiescent	1.5 VDC
Sensitivity	647-673 mV/g

This 3-axis acceleration sensor can be used to measure the velocity and position on all X, Y, and Z axis. However, in this research, only the velocity and position of the translation along X and Y axis were used.

3. Photo-relector sensor (LBR-127HLD)

Power-supply voltage	5.0 V
Peak wavelength	940 nm
Dark current	100 nA
Light current	0.2 mA

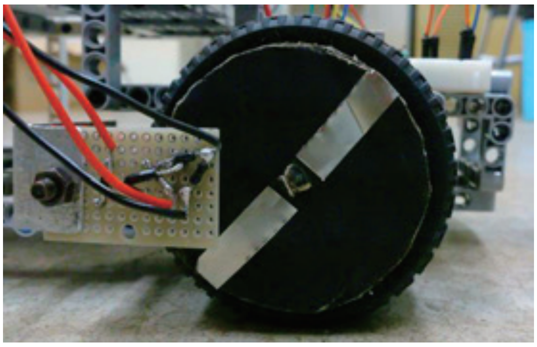

Fig. 9 Photo-reflector sensor at the rear tire

This photo-reflector sensor was used to measure the speed of tire rotation. The reflector was created manually by using a piece of black coloured paper & glossy silver coloured paper that were sticked together (Figure 9). When the tire rotates, infrared that were emitted by the sensor will be bounced back to the receiver once it hits the reflector (glossy silver paper) and thus it will be counted as 1 rotation.

All of the data and informations obtained from the sensor will be logged by using a Keyence NR-2000 data logger. The data will then be transmitted to a computer.

4.2 Control System of Model Vehicle

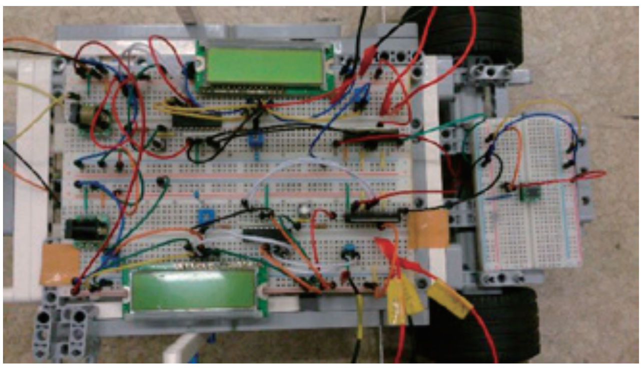

Fig. 10 Circuit board mounted on model vehicle

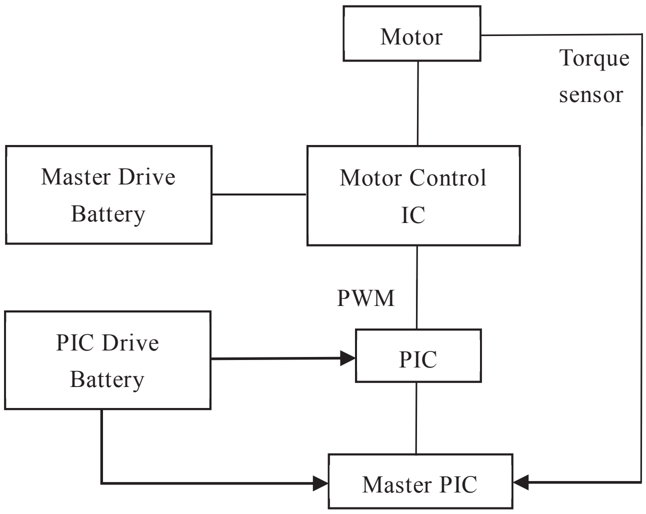

Fig. 11 Signal flow

Figure 10 shows an upper view of model vehicle mounted with a circuit board. In order to control the model vehicle, an electronic parts is crucial in the experiment. PIC or 'Peripheral Interface Controller' is used as a 'mastermind' to control the movement of the model vehicle and PIC model PIC 16F84A were used in this experiment. Each PIC is responsible to control the rotation speed of each tire and thus, 2 PIC were used in order to control both left and right rear tire rotation speed independently. The signal flow for the electronic part is as shown in Fig. 11.

4.3 Experimental conditions and method

A weight is attached at different places of the model vehicle ; in this case it was attached at the front, center and at the back of the vehicle. Thus, the rotation movement of the model vehicle is observed. The right tire is set at 15 based on the PWM value indicator which is higher than the value of left tire.

5. Results and Discussion

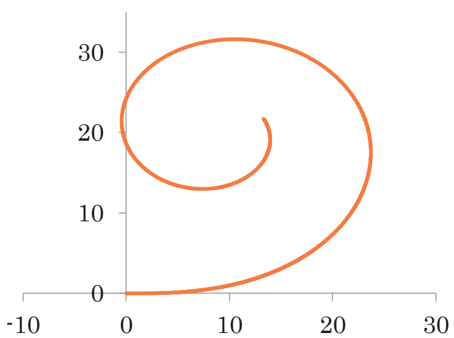

Fig. 12 Same direction with different amount of torque input

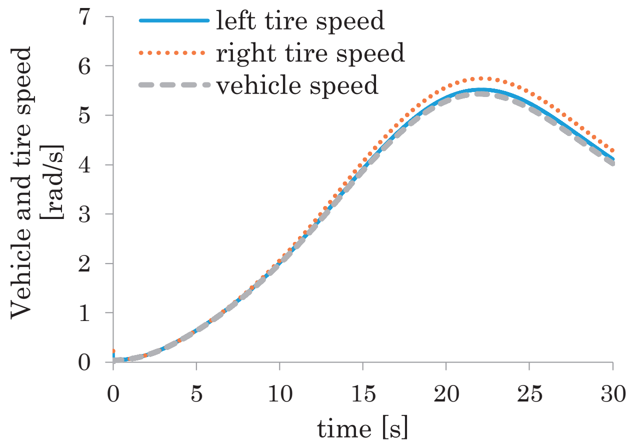

Fig. 13 Relationship of vehicle and tire speed versus time

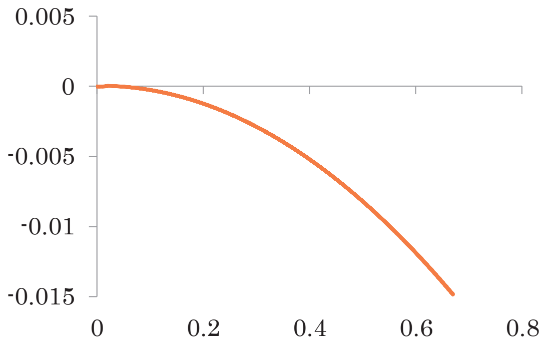

Fig. 14 Different direction with same amount of torque input

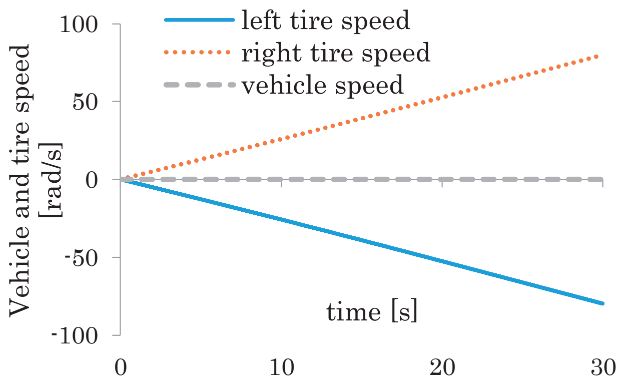

Fig. 15 Relationship of vehicle and tire speed versus time

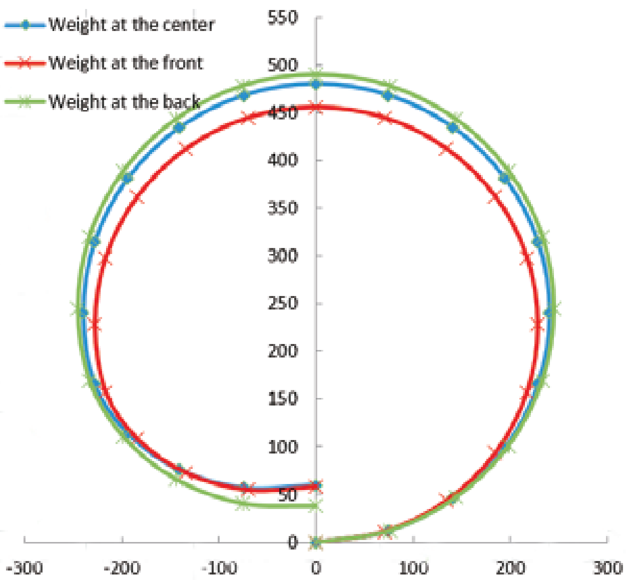

Fig. 16 Different position of Center of gravity

(1) Same direction with different amount of torque input (Simulation Case 1)

Figure 12 shows the result of the electric vehicle when cornering. The simulation is set at right wheel has a higher driving torque than the left wheel. Right wheel of the vehicle is given torque of 40 [Nm] while left wheel is set at 10 [Nm]. This shows that tire with higher amount of torque is superior and the vehicle tend to corner in the direction of tire with lower torque. Figure 13 shows the relationship between both tire speed and vehicle speed versus time. Based on the figure, tire on the right side has the most speed, followed by tire on the left side and lastly is the vehicle speed. In the definition of slip ratio, this proves that both tire are in driving condition and since the right tire has the most speed, the vehicle will tend to corner to the left.

(2) Different direction with same amount of torque input (Simulation Case 2)

In this simulation process, left tire is set at -40 [Nm] while right tire is set at 40 [Nm] and the movement result of the vehicle is shown in fig. 14. Since the vehicle has the same amount of driving torque input with opposite direction, it can be concluded that both torque are canceling each other. Thus, the vehicle does not move forward, instead it move in angular. Figure 15 shows the relationship between both tire speed and vehicle speed versus time. Since the right tire was given a positive driving torque, the vehicle speed is increasing positively over time and vice versa.

(3) Weight is attached at different position

Figure 16 shows the result of vehicle movement when a weight is attached at a different position. As for the cornering of the vehicle, the right tire is set at a value of 15 based on the PWM indicator while the left tire is set at a value of 5. Based from the simulation 5.1 result, it has been proven that the higher amount of torque value is superior and the vehicle tend to corner in the direction of tire with lower torque. Therefore, this experimental model vehicle turn in a left circular motion.

Based on the fig. 16, we can see that the circular motion is largest when the weight is put at the back of the model vehicle. This is because the center of gravity of the vehicle is located at the back, where all of the motor is attached. When the weight is put at the center or at the front of the vehicle, it will disrupt the center of gravity of the vehicle and thus the circular motion will become smaller.

6. Conclusion

Based on the result and discussion that been discussed above, we can conclude that in a situation where the driving torque are in the same direction, the higher amount of driving torque has the advantage. Thus, the vehicle will tend to steer in a direction of lower amount of driving torque. This is because higher amount of driving torque will increase the speed of the tire rotation and if there is a different of tire rotation speed, the one with faster tire rotation has the advantage and will make the vehicle steer to the opposite side. On the other hand, a same amount of driving torque with opposite direction will cause the driving torque to canceling each other and as a result, the vehicle does not move forward.

As for the experimental model vehicle, it can be concluded that the farther weight is being attached to the center of gravity of the model vehicle, the circular motion will become smaller.

Reference

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