Series Motor Four-Quadrant Direct Current Chopper: Reverse Mode, Steering Position Control with Double-Circle Path Tracking and Control for Autonomous Reverse Parking of Direct Cur...

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Series Motor Four Quadrants DC chopper

Part 8: Reverse mode, Steering position control with double circle path tracking and control for Autonomous Reverse Parking of DC Drive Electric Car.

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***Abstract*—. This paper focuses on steering position control for automatic reverse parking of dc drive electric car. The steering position control is integrate to vehicle cornering algorithm using two-turn/double circle concept. The control technique is simulated using MATLAB/Simulink and the results shown, the technique has successfully met the objective of steering position control for reverse parking and is suitable to be implemented in Autonomous DC Drive electric car.**

***Index Terms*—DC Drive, reverse parking, steering control, double circle, four quadrants dc chopper, series motor, position and speed, torque control, EV .**

I. INTRODUCTION

One of the primary reasons for the introduction of **electric cars** into the market is the concern over greenhouse gas emissions and their contribution to global warming. The purpose of creating **electric cars** that reduced or eliminated exhaust emissions was to help combat this issue [1]. Unfortunately, the price of EV and HEV is expensive making it unattainable to many people especially those living in poor countries has led to the study on the possibility for DC drive EV {1} which is known economical.

A. Literature

The study on DC drive EV, includes design of new dc motors and Four quadrants chopper to improve the performance and extend the capability such as adding mode of chopper operations [1,2,3]. Further Investigation of FQDC hardware amd simulation model includes feedback control using direct current control and Optimization using Artificial Intelligence to optimize the all operations to works a complete EV while running in different earth profiles[4,5,6,7,8,9,10,11].

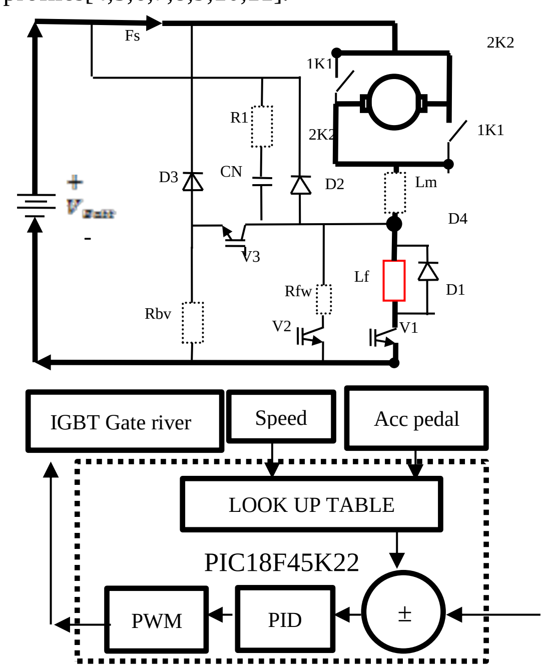

Figure1:Current paths in reverse mode.

Automatic Parking review

The Automatic parking is important when the vehicle driver happen to dealt with constrained environment where much attention and skill is required. To carry out the Automatic parking requires coordinated control of the steering angle and the surrounding to avoid collision. The parking assistance system were developed using image assistance by Mercedes , Volve and BMW. The drawback is the current technology captured image signal that has influence by the environmental brightness. A commercial version of automatic parking assistance were introduced by Toyota Motor Corporation in Toyota Prius in 2004.

Lexus 2007 LS also has Advanced Parking Guidance System.

The automatic parking consists of parking trajectory, vehicle location detection, parking space detection .turning and reverse position control.The parking space detection is used to check the available of park space for park and details is not covered in this paper.

Electric power steering (EPS)

EPS composes a motor, steering angle/encoder, reduction gear, and rack and pinion mechanism and power controller to drive the motor. The electric motor if operated can turn the wheel cause left or right or clockwise or counter clockwise cause vehicle turns left and right.

Fig.2 Complete Electrical Power Steering

The mathematical model for the dc motor for power steering

$$I_m = \frac{V_{batt} - I_m(R_m) - B_{emf}}{L_m} \quad (1)$$

$$B_{emf} = K_v I_m \omega \quad (2)$$

$$T_d = K_t I_m \quad (3)$$

$$T_d = J \frac{d\omega}{dt} + B_w + T_L \quad (4)$$

The mathematical equation for EPS

$$T_i - K_t(\emptyset_{sw} - \emptyset_{sc}) - B_{sw}\dot{\emptyset}_{sw} = J_{sw}\ddot{\emptyset}_{sw}$$

$$T_{mn} - T_f - B_{sc}\dot{\emptyset}_{sc} + K_t(\emptyset_{sw} - \emptyset_{sc}) - K_r(\emptyset_{sc} - \frac{X_r}{r}) = J_{sc}\ddot{\emptyset}_{sc}$$

$$\frac{k_r}{r}(\emptyset_{sc} - \frac{x_r}{r}) - F_r - b_r\dot{x}_r = m_r\ddot{X}_r$$

$T_i$is the input torque on the steering wheel, K_t is the stiffness of the torsion bar; $J_{sw}$and $B_{sw}$are the steering wheel angle and the steering column angle respectively. $T_{mn}$and T_f are the electromagnetic drive and the friction torque on the steering clolumn; ; $J_{sc}$and B_{sc} are the inertia and damping constant of the steering column.k_r is the stiffness between the rack and pinion; x_r is the displacement of the rack; r is the stroke ratio. The angle of the pinion is equal to the column angle.F_r is the alignment force on the rack.

Once the space has been identified next the minimum turning radius to fit the parking space is determined.

$$R_s = \frac{(l^2) - 2R_{min}(w) + (w)^2}{2(w)}$$

Where R_s is the turning radius of the first turn. R_{min} is the minimum turning radius. L is the longitudinal length and W is the lateral width for parking. The R also dependent on the Length of the vehicle, the width and the distance of back tire of the vehicle who need to park to the next vehicle which has already parked.

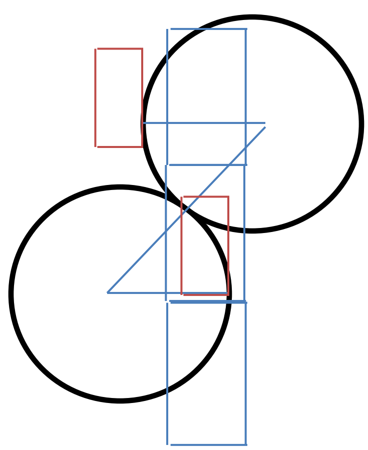

Fig 3. First and second circle for the beginning and end journey of vehicle.

Path tracking

Turning of steering to the left, right or at the center determine the vehicle turning movement. If the steering is turned to the left or right and the steering is maintained, it cause the vehicle is moved to the left and right in circular movement. While is the steering is turn at the center point the vehicle makes straight path movement.t Path tracking is the process to calculate the curvature that will take the vehicle movement from its position to a goal position.. A circle is defined in such away that it passes through both the goal point and the current vehicle position. Finally a control Algorithm chooses a steering angle in relation to this circle.

Vehicle position is calculated simply based on the accumulation of traveled distance of wheel as equation 5 and 6 in which X_r and Y_r are the current positions and X_o and Y_o are the last positions. L is the distance traversed and the $\theta$is the yaw angle.

$$X_r = X_o + lcos\ (\theta)$$

$$Y_r = Y_o + lsin\ (\theta)$$

The vehicle coordinate system is defined where the x-axis is in forward direction of the vehicle and the y-axis forms a right handed coordinate system. All coordinates used must first be transformed to vehicle coordinates in order for the algorithm to work properly. To converts coordinates located in one system into its representation in another system.Let X_r and Y_r
Be the current position of the vehicle, and X_g and Y_g
Is the goal point to be converted into vehicle coordinates. Then .

$$Y_{gv} = (X_g - X_r)\ cos(-\theta) - (Y_g - Y_r)sin(-\theta)$$

$$X_{gv} = (X_g - X_r)\ cos(-\theta) + (Y_g - Y_r)sin(-\theta)$$

Where $(X_{gv}, Y_{gv})$is the goal point in vehicle coordiantes and θ is the current vehicle heading.In the Figure above D is defined to be look ahead distance and Δy is the offset of the goal point from the origin. The required curvature of the vehicle is computed by:

$$\gamma_r = \frac{2\Delta y}{D^2}$$

METHODOLOGY

There are two required movements in automatic parking which are the vehicle movement (in reverse mode) and the steering angle movement.

For Parallel/side and reverse automatic parking, the steering angle is controlled to certain angle position using two circle turn concept**.** Then the vehicle is reversed while torque and speed of the vehicle are controlled. For parallel parking the steering angle has to be turned in to three positions while for reverse parking the steering only requires two steering positions.

The steering is in position zero or neutral at the beginning. This neutral position cause straight movement if vehicle is moved by propulsion motor. The first steering movement is as shown inFig5.

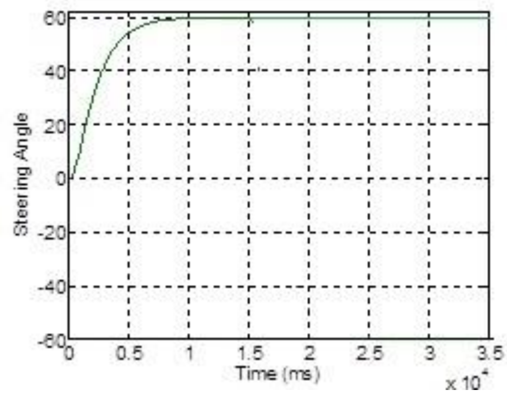

Figure 4: Steering Angle during parallel parking first turn

When the the steering position movement was completed, the propulsion motor of the EV vause vehicle movement of the vehicle to be in position as in Fig.6 with black color line. .

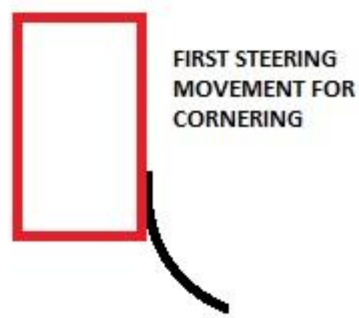

Figure 5. Vehicle movement for first steering movement,

Once the first steeinr gmovement and vehicle movement were completed the second steering need to make second movement or position as shown in Figure 7. Notice the movement is moving towards negative side.

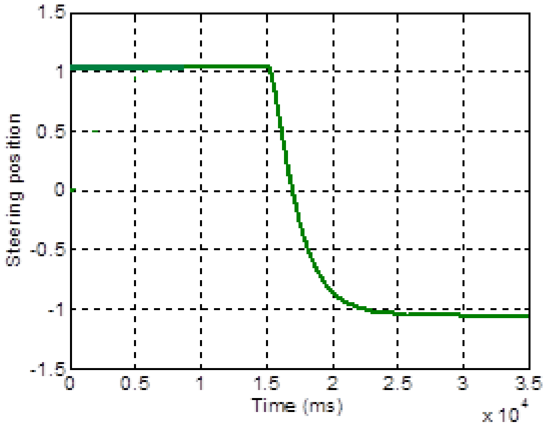

Figure 6 : Steering position during Parallel parking

The second steering movement if followed byb vehicle movement will result as shown in Fig 8.

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Figure 7 : Vehicle Movement after the seond steering position during Parallel parking. If a combination is made the vehicle movement will be as figure 9. Below.

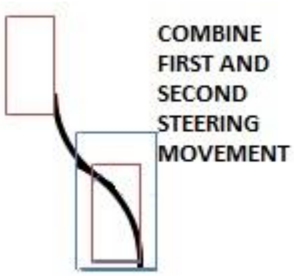

Figure 8 : Combine Vehicle Movement

Once this movement is completed the steering is required to place the steering in Neutral position as at the beginning. Fig 10. Demonstrate the action.No. 3 in the graph indicates the back to neutral action.

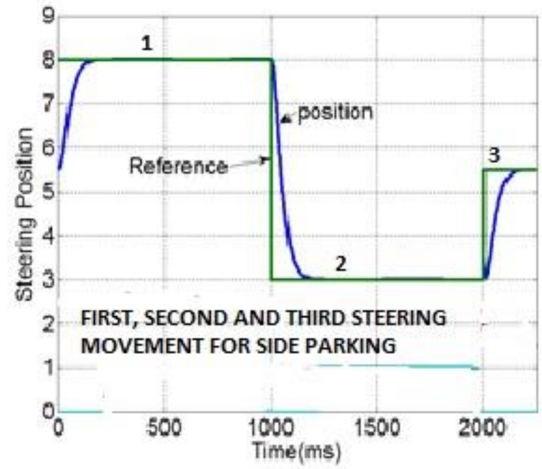

Figure 9. steering movement

Combination of Vehicle movement and steering movement are shown in Fig 11.

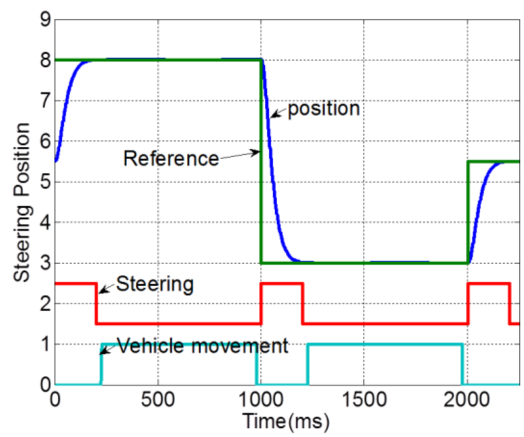

Fig. 10 shows combination of steering and vehicle movement signlas.

To the success of the automatic reverse parking requires a combination of stering movement, vehicle movement and brake action. But the vehicle movement, and brake action are nt discussed in details in this paper but the other paper. The overall action that has combination of Vehicle movement ,steering movement and brake action are shown in Fig 11..

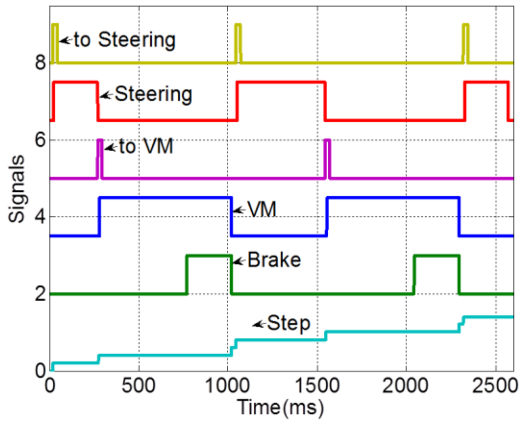

Fig. 11 shows combination of steering and vehicle movement signlas.

POSITION CONTROL OF STEERING

Pid controller is used for position control of the vehicle steering. The steering angular position can be obtained by Integration of the mathematic equation 4. The equation 4 results in angular speed. To obtain angular position the integrator is added to the output of angular speed. The steering speed is not controlled because the motor is connected to gear where the speed is limited to the safe and convenience point. The position feedback sensor can be potentiometer or encoder provides signal feedback to the The PID controller. The mathematical equation for PID is as shown in Eq. 10.

$$K_p + \frac{K_i}{s} + K_d s = \frac{K_p s + K_i + K_d s^2}{s}$$

PI Controller

Tuning PID using SISOTOOL

Equations 1 to 4 can be group to form Physical based model which represent the speed. The steering angular position can be determined by adding integrator and the speed output. The MATLAB/Simulink linearize tool can be used to linearize the differential equation and finally tuned the PID. The Matlab/Simulink PID drag and drop icon has menu which can be click to tune the PID automatically. . For the tuning the MATLAB/Simulink using SISO tool the Physical based model has to be transformed to Transfer function model using Matlab/Simulink system identification. The tool used to find the system order Finally Using SISO tool the transfer function for steering position system determined and the PID controller gain can be obtained. The Siso tool as well used to test system stability using root locus or bode plot. The PID controller gain can be obtained using PID auto tune function.

SISO tool gives the compensator circuit as

$$C = 2.6738e6\ x\ \frac{(1 + 0.38s)}{s}$$

Whereby $K_p = 2.6738e6$, $z = \frac{1}{0.38}$, $z = 2.6315$, $K_i = K_p z$, $K_i = 7{,}036{,}315.7$

Using SISO tool the transfer function for Field current and speed can be loaded so that several can be done to test system stabilitywhich are under root locus and bode plot, and to design PID controller using PID auto tune function.The result of PID controller as seen in figure below

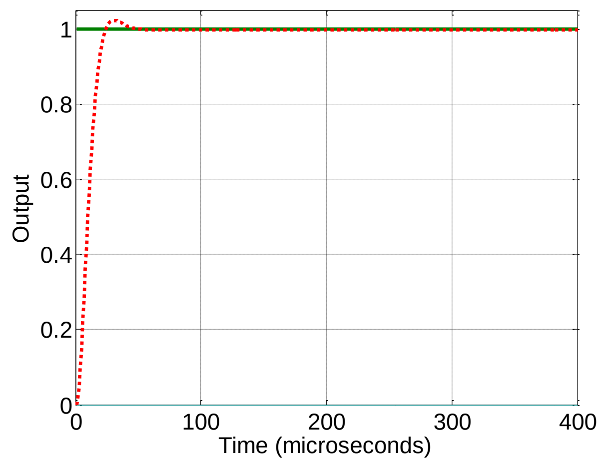

Figure 12. Results of Tuning with MATLAB/Simulink Toolboxes

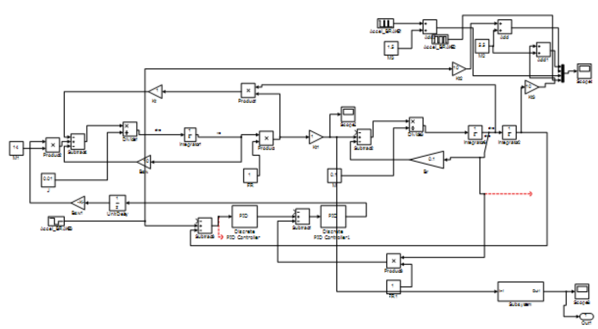

Figure 13: Matlab/Simulink Physical Based model

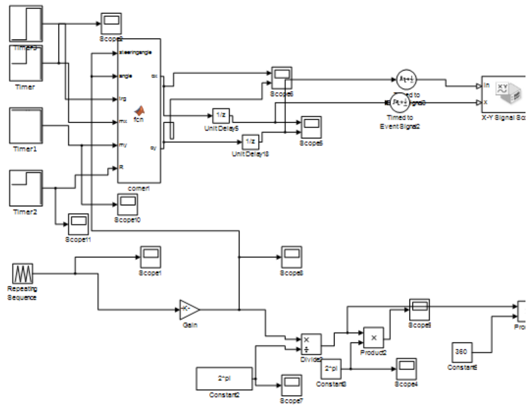

Figure 14: Matlab/Ssimulink simulation model for steering double circle

A simulation model is developed to test the control technique. As the position for angular and displacement are known, the feedback control for speed and torque for vehicle movement and steering position control using PID controller can be performed.

For monitoring the car trajectory a simulation model using mathematical equation as shown in Figure 15 is established.

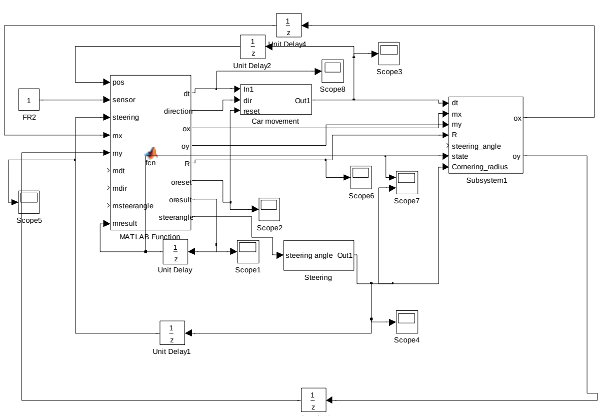

Figure 15: Simulation model of Auto Parking

Results

For the parallel parking the steering angle position control is as shown in figure 16. Two movement of steering angle are shown. At First the steering is steered to the right followed by the vehicle movement. Next the steering makes movement to the left and then followed by the vehicle movement.

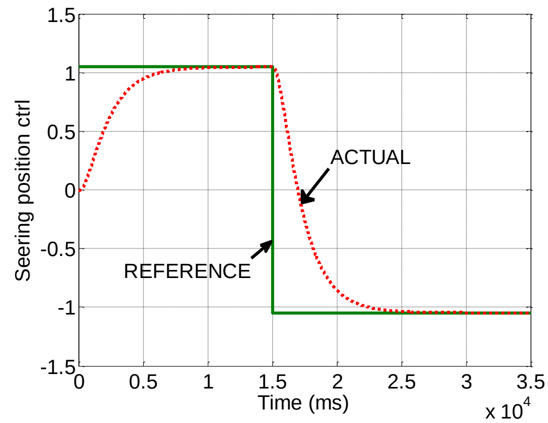

Figure 16: Steering position fedback control

. The sequence is first steering angle makes first movement and followed by vehcicle movement. Once the vehicle movement has completed the steering is tehn makes movement again for different steering angle. Finally the vehicle movement is then followed. During the sttering is mking movement the vehciel is completely stop. Figure 12 shown the vehicle trajectory resulted from the combination of vehicle movement and steering movement for automatic parallel parking. In figure 17 the vehicle movement position is shown

Figure 13 shows the vehicle trajectory resulted from a combination of vehicle and steering movement for automatic reverse parking.

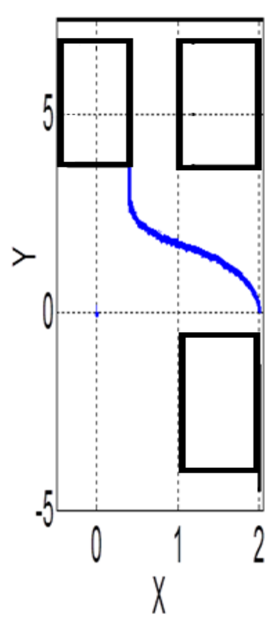

Figure 17: Paralle park measured from back tire right side

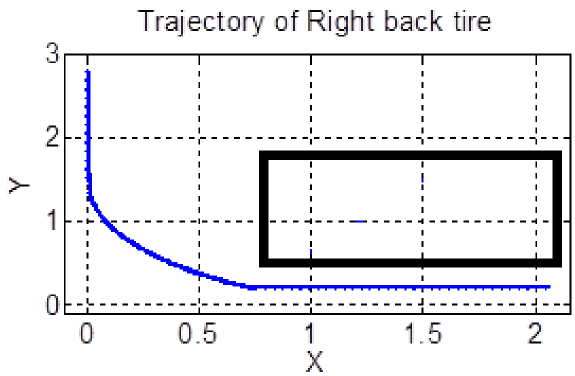

Figure 18: Trajectory of Right back tire with reverse parking

I. CONCLUSION

The control technique proposed for automatic parking for Parallel and reverse parking has successfully being performed and simulated. The speed ,torque and position of steering and vehicle movement has successfully been controlled for the application of Automatic parking for reverse and parallel park. DC drive Electric Car powered by four quadrants drive dc chopper for series motor is suitable for the application of DC Drive Electric car and can have an automatic car Parking as an extra feature .

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