The Vehicle Steer by Wire Control System by Implementing PID Controller

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***Abstract*— The latest technology of vehicle steer-by-wire (VSBW) system has promised significant improvement in vehicle safety, dynamics, stability, comfort and maneuverability. Due to complete separation between steering wheel and the front wheels gives the practical problems for steering control especially on directional control and wheel synchronization of vehicle. This paper presents investigations into the development of PID control scheme for directional control and wheel synchronization of a VSBW system. Two PID controllers are used to control the steering wheel angle and front wheel angle. The PID controllers use the front wheel tracking error to generate controlled steering angle. The Ziegler Nichols method is used for tuning the PID parameters. The implementation environment is developed within Matlab/Simulink software for evaluation of performance of the control scheme. Implementation results of the response of the VSBW system with the PID controller are presented in time domains. The performances of control schemes are examined in terms of input tracking capability, wheel synchronization and time response specifications with the absence of disturbances.**

***Index Terms*— Directional control, PID controller, vehicle steer by wire, Ziegler-Nichols**

I. INTRODUCTION

Traditionally, the steering method for vehicle uses a mechanical linkage between the steering wheel and the front wheels. In the recent decades, vehicle steer by wire (VSBW) system has become one of the major interesting research subjects due to the main characteristic which is to completely eliminate as many mechanical components (steering shaft, column, gear reduction mechanism, etc.) as possible as shown in Figure 1 [1].
Due to the mechanical coupling between the steering wheel and the front wheel system are eliminated, a VSBW system is expected to provide an advanced steering function [2]. The front wheel needs to follow the input from the driver precisely. But in the real situation, the VSBW system is faced many disturbances such as uneven condition of the road and parameter uncertainties of the system. The control approach for controlling the direction of the front wheel is a challenging task. The reliable and robust control scheme needs to be developed

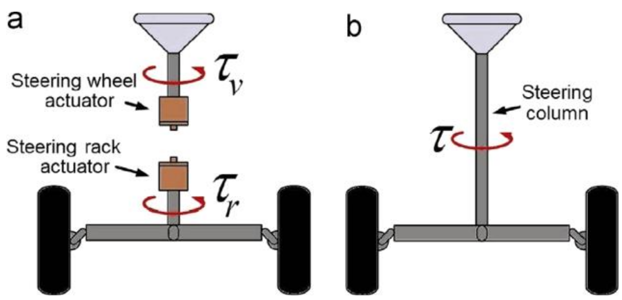

Figure 1: (a) VSBW (b) Conventional Steering System

There have been several studies in the literature reporting on the modeling and control of VSBW system. The PID controller has been introduced in [2] to control the wheel synchronization and they also introduced a new feedforward variable steering ratio based on under propensity equation method. The model reference control (MRC) strategy has been proposed in [3] where the measured external force/torque is used as an input to a reference model to calculate its output and where the real VSBW system is controlled appropriately to track the reference system output. In [4], they have proposed the yaw stability control algorithm to control the lateral and yaw motion of the vehicle by using feedback from both yaw rate and front steering angle feedback gains with respect to vehicle speed. But in this research, they used vehicle dynamics model to simulate their work which was very complicated. Another research that used vehicle dynamics model is presented in [5]. They have proposed the continuous feedback control method based on the synchronization characteristics to control the chaotic motion to improve vehicle handling and steering performance. Another method to stabilize the vehicle’s yaw movement is using the virtual sensing relative to estimating the vehicle's yaw rate by only measuring the articulation angle and vehicle speed [6]. This method can reduce sensor cost, maintenance, and machine downtime. Bilateral control method of torque drive and angle feedback have been proposed in [7]. This method is controlling steering wheel block and steering actuator as master-slave plants by using the PID controller. In [8], they have presented the control strategies of steering wheel using PID controller and Active front steering (AFS) controller for front wheel system. An Adaptive Sliding Mode (ASM) controller has been implemented in VSBW system that can cope with parametric uncertainties and estimate the coefficient of the self-aligning torque [9]. Several attempts have been made to control the VSBW system by using Fuzzy logic controller such as in [10,11,12,13]. Nevertheless, the implementation of Fuzzy logic controller requires a large amount of design effort to tune the membership functions.

Most of existing control scheme of SBW system stress on the vehicle yaw stability which is involved deep on vehicle dynamics model. Only a few researches that focus on steering wheel model and front wheel model system such as in [2,8,11,13]. In [2], they used PID controller to control the front wheel angle with existence of disturbance and torque. The proposed controller was able to reduce the disturbance error and the front wheel angle is increased and proportional to the vehicle speed. Thus, the proposed control strategy improved maneuverability and stability of the system.

This paper presents an investigation into the development of robust PID controller scheme of directional control and wheel synchronization of VSBW system. The PID controller parameters (Kp, Kd, Ki) is tuned by using Ziegler Nichols method. The implementation environment is developed within Matlab/Simulink for evaluation of performance of the control scheme. The performances of PID control scheme are examined in terms of input tracking capability, wheel synchronization and time response specifications with the absence of disturbances. The rest of the paper is structured as follows: Section 2 describes the modelling of the VSBW system derived using Newton's law. Section 3 describes the design of PID controller. Section 4 presents the simulation setup. Simulation results are presented in Section 5 and the paper is concluded in Section 6.

II. MODELING OF VEHICLE STEER BY WIRE SYSTEM

This section provides a brief description on the modelling of VSBW system as a basis of a simulation environment for the development and assessment of the PID control technique. The VSBW system is mathematically modelled using Newton's law to derive the dynamic equation for wheel angle displacement about the kingpin axis [14]. The driver input torque, Tdriver, at the steering wheel is the primary external input of the steering systems and the wheel rotational angles are the desired outputs. The distinguishing feature of the VSBW configuration is the physically decoupled driver interface and rack assembly. The torque input at the steering wheel is transmitted by means of electric signals to the rack's servo motors to obtain the desired wheel angle for vehicle directional control [15]. The lumped parameter of non-linear mathematical model for VSBW system is summarized in Table 1. The dynamic equations for the steering wheel, electric actuators, rack displacement and wheel angular displacements are presented.

A. Steering Wheel System Modelling

Figure 2 shows the steering wheel diagram. In steering wheel system, the input to the system is the steering angle, θ_{sw} and driver torque, T_{driver}. While motor torque, T_{M1} and torque friction, T_{frc} reacted as a disturbance. The output of the system is the steering motor current, i_{a1} and steering motor angular displacement, θ_{M1}. B_{sc} is steering lumped inertia, R_1 is a motor electrical resistance, L_1 is a motor electrical inductance, I_{M1} is a lumped inertia motor and K_{b1} is a steering motor emf. The mathematical equations of the steering wheel system are given as follows:

Steering wheel Angle:

$$\ddot{\theta}_{sw} = \frac{1}{I_{sw}}\begin{pmatrix} T_{driver} - B_{sc}(\dot{\theta}_{sw} - \dot{\theta}_{M1}) \\ -K_{S1}(\theta_{sw} - \theta_{M1}) - T_{fr,c} \end{pmatrix} \quad (1)$$

Steering motor angular displacement:

$$\ddot{\theta}_{M1} = \frac{1}{I_{sw}}\begin{pmatrix} -B_{M1}\dot{\theta}_{M1} - B_{sc}(\dot{\theta}_{M1} - \dot{\theta}_{sw}) \\ -K_{S1}(\theta_{M1} - \theta_{sw}) + T_{M1} \end{pmatrix} \quad (2)$$

Steering motor current:

$$\frac{di_{a1}}{dt} = \frac{1}{L_1}(-R_1 i_{a1} - k_{b1}\dot{\theta}_{M1} + V_{S1}) \quad (3)$$

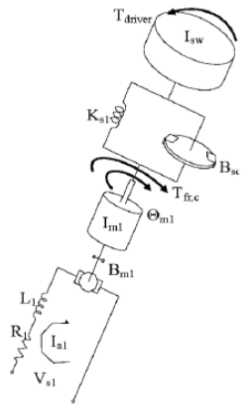

Figure 2: Steering wheel diagram

B. Front Wheel System Modelling

Figure 3 shows the front wheel diagram. The steering motor angular displacement, θ_{M1} is considered the input of the front wheel system. The mathematical equations of the front wheel system are written as follows:

Front motor angular displacement:

$$\ddot{\theta}_{M2} = \frac{1}{I_{M2}}\begin{pmatrix} -B_{M2}\dot{\theta}_{M2} - T_{M2} \\ -K_{S2}(\theta_{M2} - y_{rack_f}/r_p) \end{pmatrix} \quad (4)$$

Front motor current:

$$\frac{di_{a2}}{dt} = \frac{1}{L_2}(-R_2 i_{a2} - k_{b2}\dot{\theta}_{M2} + V_{S2}) \quad (5)$$

Rack displacement:

$$\ddot{y}_{rack_f} = \frac{1}{m_{rack_f}}\left(-\frac{2K_{Lf}}{r_L}\left(\frac{y_{rack_f}}{r_L} - \delta_F\right) - F_{fr,rack_f} - B_{rack_f}\dot{y}_{rack_f} + \frac{K_{S2}}{r_p}\left(\theta_{M2} - \frac{y_{rack_f}}{r_p}\right)\right) \quad (6)$$

Front wheel rotational angular acceleration:

$$\ddot{\delta}_F = \frac{1}{I_f}\begin{pmatrix} -K_{Lf}(\delta_F - y_{rack_f}/r_L) \\ -T_{fr,kpf} - B_{kpf}\dot{\delta}_F - M_z \end{pmatrix} \quad (7)$$

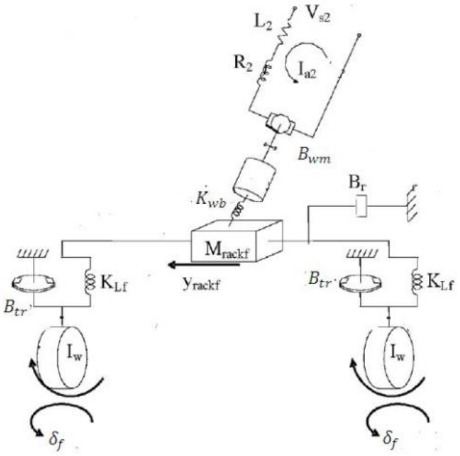

Figure 3: Front wheel diagram

Table1:
The parameter for VSBW system

Parameter	Value	Units
B_{kp}	30	Nms/rad
B_{rack}	25	Nms/rad
B_{sc}	13.6e-02	Nms/rad
B_{mi}	1	Nms/rad
B_{rack}	25	Nms/rad
K_{si}	3500	Nm/rad
T_{frc}	random	Nm
I_{sw}	7.9e-03	Kgm^2
T_{M1}	random	Nm
L	2e-03	H
R_1	4.6	Ω
R_2	0.6	Ω
k_{bi}	35.3e-02	Vs/rad
I_{M2}	1.9	Kgm^2
r_p	3.5e-02	m
r_L	0.3	m
m_{rack}	2.0	kg
k_{Lf}	26000	Nms/rad
$F_{fr,rack}$	9	Nm
T_{frkp}	2	Nm

III. Controller Design

In this section, PID control scheme for directional control and wheel synchronization of a VSBW system is proposed. The block diagram of the VSBW system is shown in Figure 4. The input for the system is a torque driver, T_{driver}. Two PID controllers are used which are for steering wheel system and front wheel system. First PID controller is responsible to compensate the error produced by steering wheel angle, θ_{sw}. Then, θ_{sw} is fed to the input of the front wheel system. The second PID controller in front wheel system will control the wheel displacement, δf to operate the system according to the input.

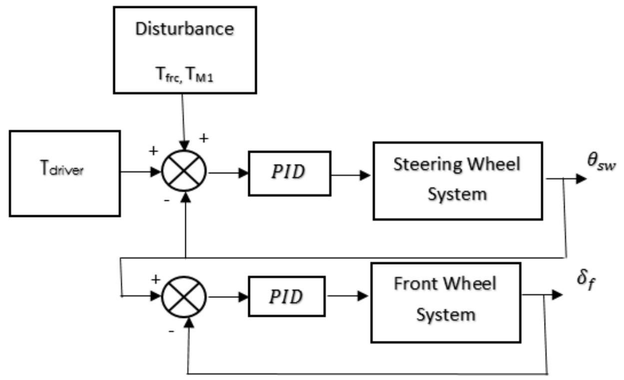

Figure 4: Block diagram of VSBW system

The PID parameters are tuned by using Ziegler Nichols method. For the Ziegler-Nichols method, the critical gain, K_{cr} and critical period, P_{cr} have to be determined by setting the Ki = ∞ and Kd = 0. Then, the value of Kp is increased from 0 to a critical value and the gain were adjusted until the response oscillated with a constant amplitude.

IV. Simulation Setup

In this section, the proposed control scheme is implemented and tested within simulation environment of VSBW system and the corresponding results are presented. The implementation environment is developed within Matlab/Simulink software for evaluation of performance of the control scheme. Figure 5 shows the simulation setup done in Matlab/Simulink. There are several simulations have been done which are system without disturbance and system with disturbance. Two test input signals are used for the system which are step input and sinusoidal input. The performances of the control schemes are assessed in terms of time response specifications, directional control and front wheel synchronization. The PID parameters for steering wheel angle obtained from the Ziegler Nichols method are Kp = 30, Kd = 0.08 and Ki = 70 while for front wheel system are Kp = 320000, Kd = 500 and Ki = 80000.

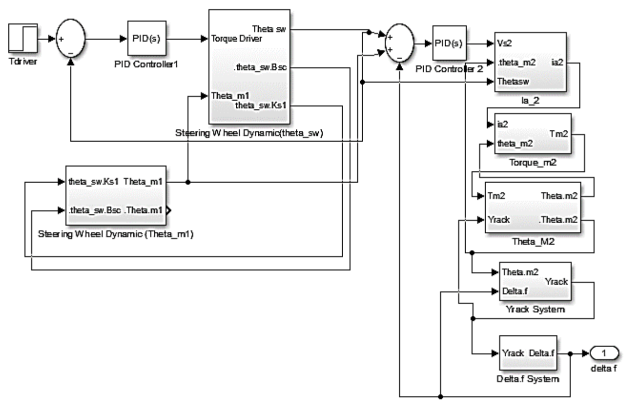

Figure 5: Simulation setup using Matlab/Simulink

V. Results And Discussion

Figure 6 shows the step response for steering wheel angle and front wheel angle. The results show that steering wheel angle can track the desired T_{driver} with zero steady state error and percentage overshoot, %OS = 10%.

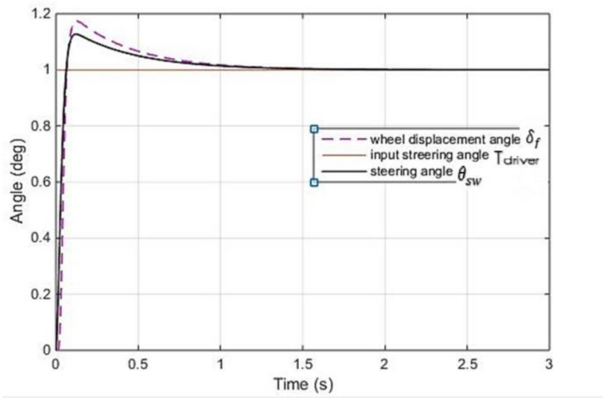

Figure 6: Step response for θ_{sw} and δ_f

The front wheel displacement angle can track the steering wheel angle with zero steady state error. But the percentage overshoot, %OS is higher than θ_{sw} which is 19%. Both responses have an identical settling time, T_s which is less than 1 second.

To test the reliability and robustness of the controller, the motor torque, T_{M1} and torque friction, T_{frc} were applied to the system to react as a disturbance. In Matlab/Simulink, the random signal is used as a disturbance for the system. Figure 7 shows the step response for steering wheel angle and front wheel angle with disturbance. The results indicate that the steering wheel angle and front wheel angle is able to track the desired input with a maximum residual of $\pm$ 0.1^o though the system has a disturbance.

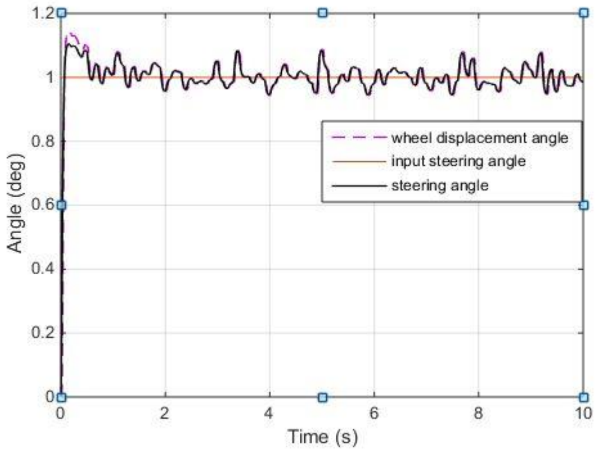

Figure 7: Step response for θ_{sw} and wheel displacement angle with disturbance.

The system is tested with another signal which is sinusoidal input to test the repetitive operation. Figure 8 shows the results for steering wheel angle and front wheel angle with sinusoidal input. From the result, it clearly shows that both angles can track the desired input with minimal error about 0.1^o. In frequency response, the VSBW system is stable with phase margin is 56.7 o as shown in Figure 9. The findings provide evidence that PID controller can improve the performance of the VSBW system in terms of input tracking capability, directional control and wheel synchronization.

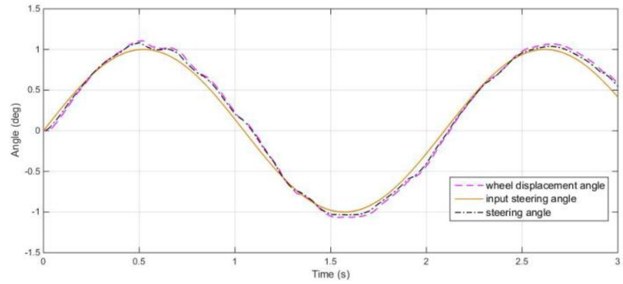

Figure 8: Sinusoidal response for θ_{sw} and δ_f

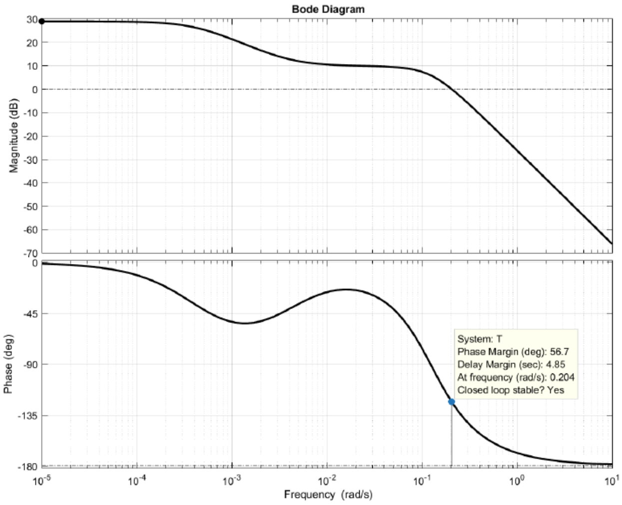

Figure 9: Bode diagram for VSBW system

VI. CONCLUSION

Investigations into directional control and wheel synchronization of a VSBW system using the PID controller have been presented. The proposed control schemes have been implemented and tested within simulation environment of a VSBW system. The performances of the control schemes have been evaluated in terms of input tracking capability, wheel synchronization and time response specifications with the absence of disturbances. Nevertheless, the implementation of PID controller requires a large amount of design effort to tune the PID parameters. Finally, it is concluding that the PID controller is capable to improve the performance of VSBW system.

ACKNOWLEDGMENT

This work was supported by Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka, especially Robotic, Industrial and Automation (RIA) Research Group under research grant PJP/2015/FTK (21C)/S01441.

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