Development of force feedback in steering systems for virtual driving simulator

by Joga Setiawan

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Abstract. In steer-by-wire (SBW) vehicles, the elimination of the rigid mechanical column shaft would require the system to generate an artificial feedback torque which should produce similar driving feeling and behavior as to the conventional steering system. The objective of this study is to evaluate the characteristics of force feedback inside SBW vehicle for driving simulator utilizing Logitech G27 steering wheel. The model of the system is developed in Matlab/Simulink/3D Animation. A J-turn test is performed to see the resulting handwheel torque and its effect on the vehicle dynamic. The evaluation shows that the results are reasonable such that the driver of the simulator can feel the similar forces coming from the real road.

1 Introduction

A steering wheel is one of the contributing factors that plays an important role in enhancing the safety of the passenger beside maintaining the vehicle stability. Inside a typical steering system, the driver's steering input is transmitted by a steering shaft through a type of gear mechanism to generate steering motion at the front wheels. Nowadays, power steering assist has become a standard built-in feature inside most of road vehicles. The power steering amplifies the driver's-applied torque at the steering wheel such that steering effort is reduced.

Steer-by-wire (SBW) system utilizes the by-wire technology to perform and also augment existing functions of mechanical steering systems. The term "by-wire" can also be referred to as the replacement of mechanical controls to the electronic system. SBW systems have no mechanical linkage (steering column) between the steering wheel and the rack and pinion gear system [1]. SBW system omits the intermediate shaft available in conventional vehicles, which allows the possibility of independently commanding the roadwheels through both driver and lane-keeping assistance system [2]. This study produces an algorithm for producing steering feedback torque using Simulink for virtual experimentation.

2 Research Methodology

2.1 Bicycle Model with Artificial Force Feedback Model

A bicycle model of a car is used as a reference model for three degree-of-freedom (DOF) in the driving simulator as shown in Fig. 1(a) and represented by Eqs. (1-3). An artificial force

feedback model for a simple conventional steering system shown in Fig. 1(b) will be integrated with the bicycle model. The last step is to develop the simulation on the Simulink for different maneuver specified later on, inputted by the Logitech G27 steering wheel with the 3D car animation.

$$\dot{V}_x = \frac{F_x}{m} + rv_y \tag{1}$$

$$\dot{V}_y = \frac{1}{mv_x} - (-aC_{af} + bC_{ar})r - \frac{1}{mv_x}(C_{af} + C_{ar})v_y + \frac{1}{m}C_{af} + C_{ar}\delta_F - rv_x \tag{2}$$

$$\dot{r} = \frac{1}{I_{zz}v_x} - (-a^2C_{af} - b^2C_{ar})r - \frac{1}{I_{zz}v_x}(aC_{af} - bC_{ar})v_y + \frac{1}{I_{zz}}aC_{af}\delta_F \tag{3}$$
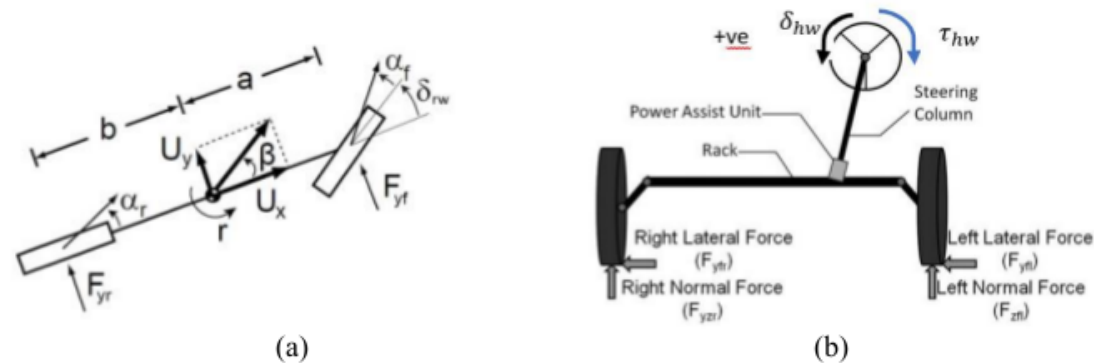

(a) (b)

Fig. 1. (a) Simple bicycle model extracted from [3], (b) Simple conventional steering system taken from [4] with some modifications to signify the steering wheel angle and handwheel torque.

Table 1. Parameter values for simulation

Parameter	Value	Units	Parameter	Value	Units
α	1.02	m	k_{db}	0.01	-
α_f	0.10	rad	k_{jack}	250	-
b	1.48	m	k_{tire_mom}	0.035	-
b_{system}	0.015	N.m/rads^{-1}	m	1200	kg
C_{af}	110000	N.rad^{-1}	μ	0.90	-
$\Delta_{damping}$	0.10	N.m/rads^{-1}	σ_{ps}	0.20	-
$\Delta_{inertia}$	1.00	kg.m^2	t_m	1.00	cm
δ_{db}	0.05	rad	t_p	0.58	cm
δ_{rw}	1.00	rad	t_{po}	1.00	cm
F_{yf}	-7030	N	τ_{allign}	11100	N.m
F_{zf}	9680	N	$\tau_{asstd\_tire\_mom}$	-9820	N.m
F_{yf}	9.81	N	τ_{damp}	0.10	N.m
G	17	-	τ_{hw}	-343	N.m
γ	0.20	-	$\tau_{inertia}$	1.00	N.m
I_{add}	0.01	-	τ_{jack}	-250	N.m/rad
I_{zz}	1552	kg.m^2	τ_{motor}	-343	N.m
J_{system}	0.0014	kg.m^2	τ_{tire_mom}	10800	N.m
k_{damp}	0.10	-	Vx_{mph}	31.07	mph

The steering sense can be developed in an SBW system utilizing force feedback (FFB) interface, depicted in Fig. 1(b) where it utilizes Eqs. (4-5) generate the handwheel torque, τ_{hw}. The handwheel torque is felt by a driver once the driver turns the steering wheel. Three

dominant torques which play a role in producing the steering feel [5]: torques due to damping and inertia, and tire moment torque due to power assist.

$$\tau_{hw} = \tau_{motor} + J_{system}\ddot{\delta}_{hw} + b_{system}\dot{\delta}_{hw} \tag{4}$$

$$\tau_{motor} = \tau_{damp} + \tau_{inertia} + K\tau_{assisted\ tire\ moment} \tag{5}$$

The details of Eqs. (4-5) are available in [4] and [5]. The parameter values for simulation are given in Table 1. The calibration of the Logitech G27 steering resulted in the torque T in Newton shown in Eq. (6),

$$T = 3.0156\,U_s + 0.1161 \tag{6}$$

where U_s is the value specified in Simulink for the force feedback port of Joystick block.
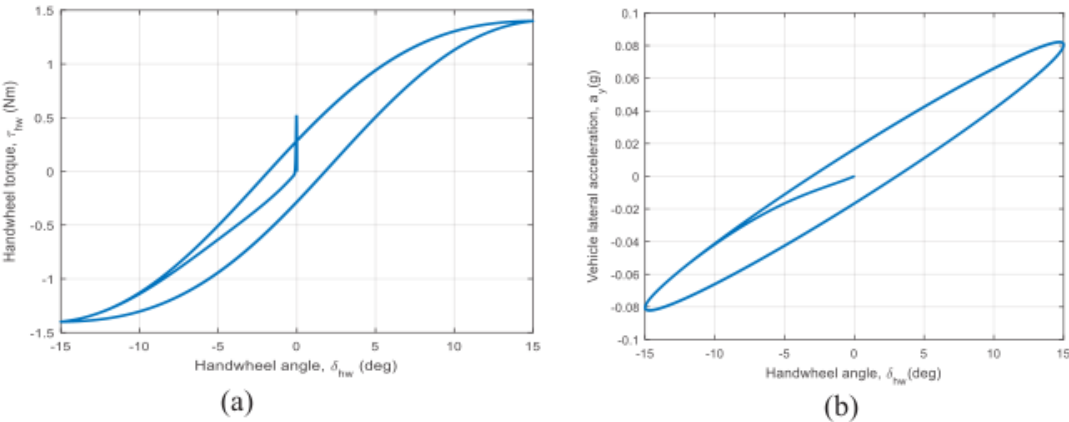

Fig. 2. (a) Hand wheel torque as function of handwheel angle, (b) Vehicle lateral acceleration as function of handwheel angle.

2.2 Validation test

For validation purposes, weave test is performed to obtain several measures which includes the handwheel angle (δ_{hw}), vehicle lateral acceleration (a_y) and handwheel torque (τ_{hw}) as well as to evaluate on-center handling. On-center handling can be defined as the steering feel generated of a vehicle during straight-line driving and in negotiating large radius bends at some high speeds. These conditions were obtained from the input parameters performed by Balachandran and Gerdes [6], where weave manouver tests were conducted.

Weave test generates the characteristics to evaluate the steering feel and steering precision around the central position. During this test, steering angle oscillates sinusoidally with constant amplitude and frequency around set vehicle speed of 50 km/h as shown in Fig. 2 which has a similar pattern as in [7]. Validation of the result is performed by a weave test showing the characteristics of the steering feel/force feedback produced. It is shown in Fig. 3 in which the graphs consist of handwheel angle (δ_{hw}), vehicle lateral acceleration (a_y) and handwheel torque (τ_{hw}) as function of time at a constant speed of 50km/h.

3 Analysis of J-Turn Test

This J-turn was selected to study the performance of the force feedback inside a SBW steering system. The virtual experiment is conducted with the help of 3DView of the vehicle as shown

in Fig 4. Four different kinds of graph, starting with the steering wheel angle, throttle, brake as the function of time and lastly the position of the car on the x and y position as shown in Fig. 5. This test illustrates the dynamic vehicle behavior when entering a curve. The car has an initial velocity, v_x. In this test, this initial velocity is set to 60 km/hr. Five seconds after the simulation is started, input to the steering angle is set to 85° to the right, and 10 seconds later the steering angle is set back to zero. The behavior of the vehicle during the virtual experiment is shown in Fig. 6 which includes the handwheel torque, yaw velocity, longitudinal acceleration and lateral acceleration.
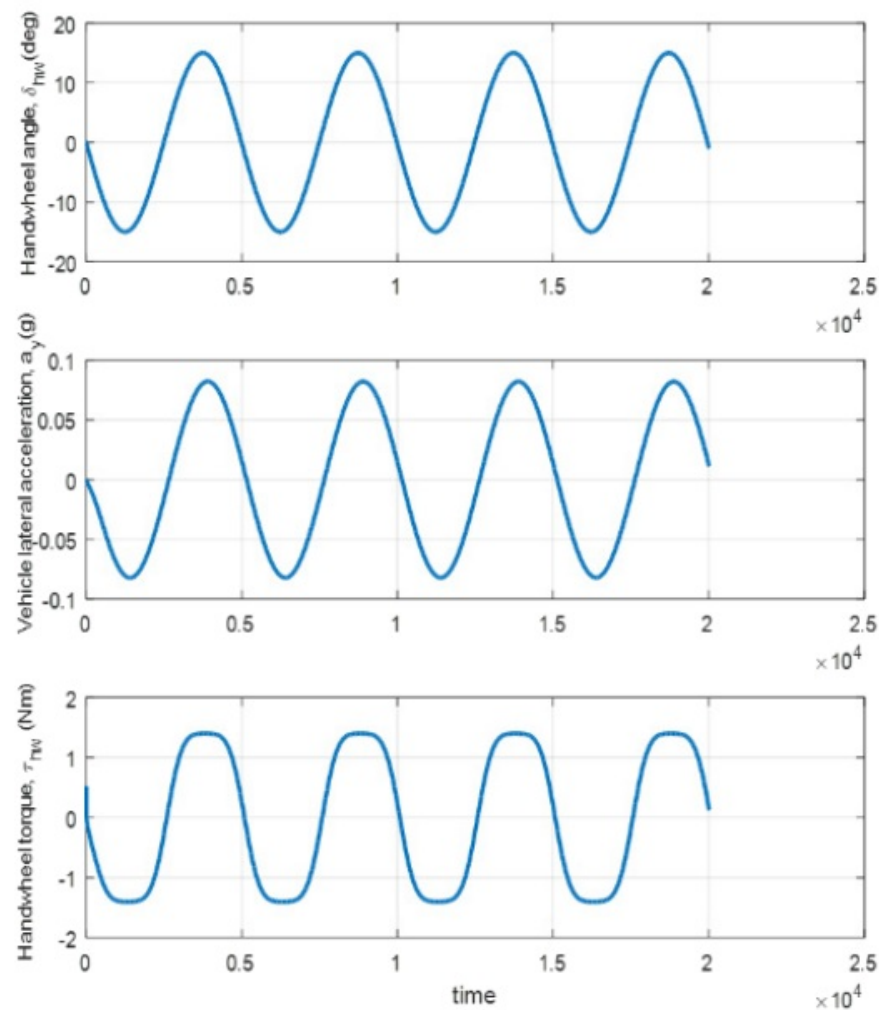

Fig. 3. Handwheel angle, vehicle lateral acceleration and handwheel torque as function of time.

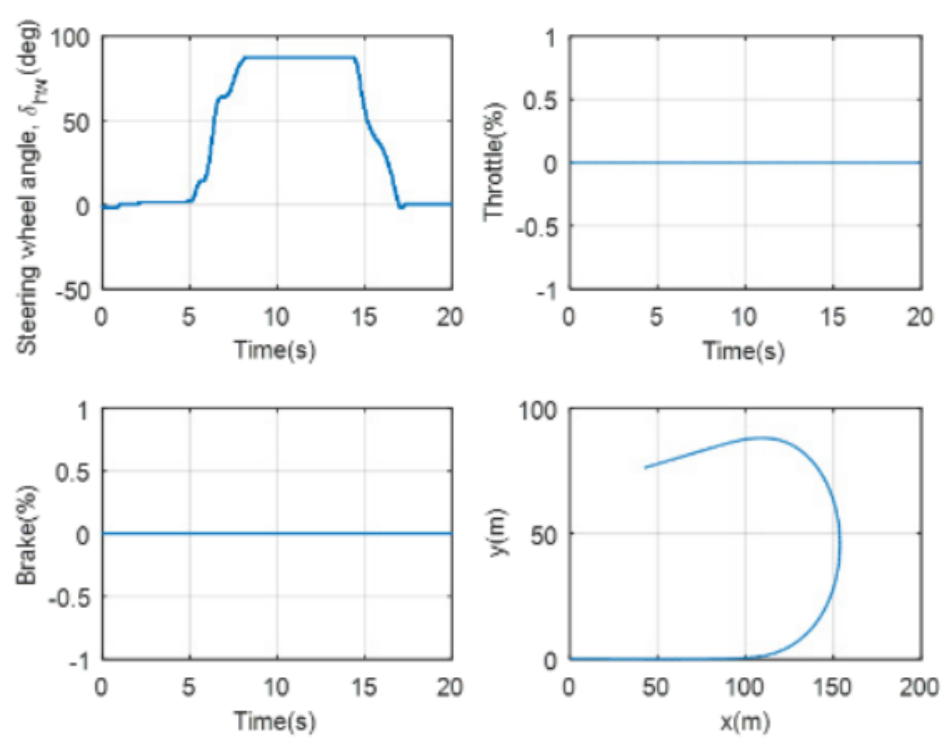**Fig. 4.** View of Car in 3D animation of Matlab

Fig. 5. Steering wheel angle, throttle, and brake as function of time, and x-y position of vehicle during a J-turn test.
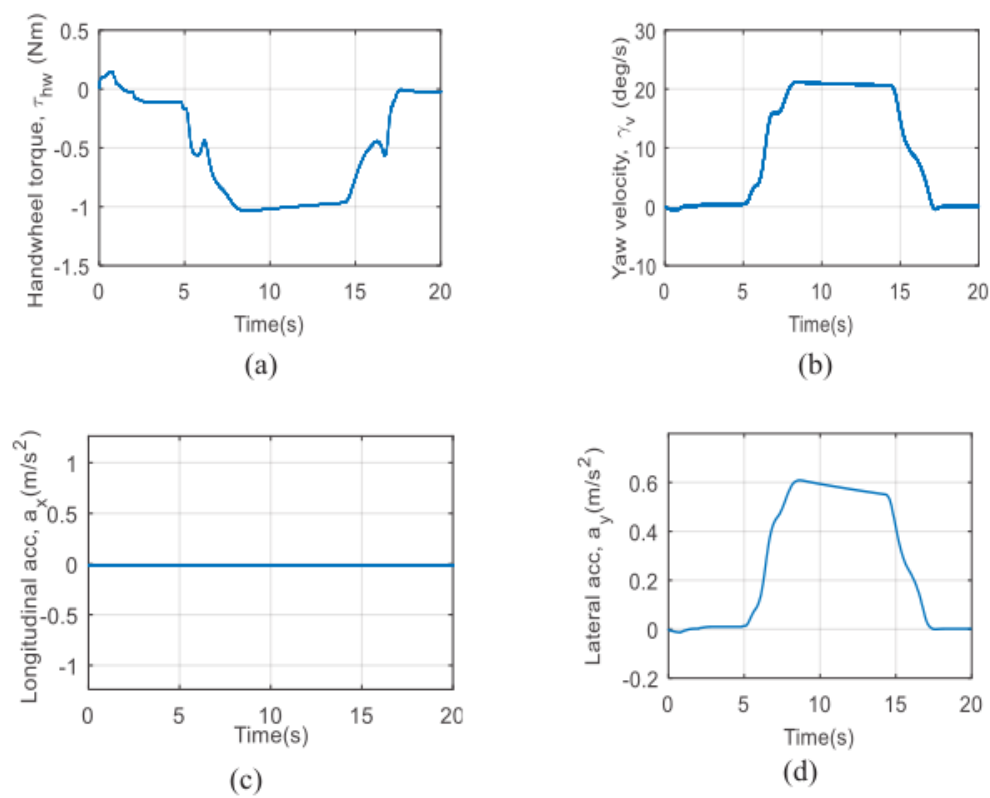

Fig. 6. (a) Handwheel torque, (b) Yaw velocity, (c) Longitudinal acceleration, (d) Lateral acceleration.

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4 Conclusions

In this study, handwheel torque that contributed the biggest value to the force-feedback had been modeled. An artificial force-feedback behavior in a steer-by-wire vehicle had been successfully produced using Simulink for a virtual vehicle simulator. An experiment had been performed to show vehicle dynamic behavior during a J-turn test. Calibration test played a crucial role to identify the appropriate amount of constant gain in generating force-feedback signal. The driving simulator being developed has reasonably made the driver of the simulator feel the similar forces coming from a real road.

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