

**TECHNICAL PAPER FOR STUDENTS AND YOUNG ENGINEERS****- FISITA WORLD AUTOMOTIVE CONGRESS, BARCELONA 2004 -**

TITLE:

**A STUDY OF EFFECT OF STEERING GAIN AND STEERING TORQUE  
ON DRIVER'S FEELING FOR SBW VEHICLE**

Topic:

- FUTURE AUTOMOTIVE TECHNOLOGY       INTELLIGENT TRANSPORTATION SYSTEMS  
 USER FRIENDLY AUTOMOBILE       ADVANCED PRODUCTION AND LOGISTICS  
 VEHICLES & THE ENVIRONMENT

Author(s):

Yu Wun CHAI\*

Nationality:

Malaysian

University / Institution:

Kanagawa Institute of Technology

National Society:

 YES       NO

Name of the National Society:

Abstract:

Steer-By-Wire (SBW) system offers the possibility to set freely the relation between the tire steer angle with the driver's steer input (steering gain), and also the steering reactive torque with the driver's input, respectively. This paper concerns about the study of effect of steering gain and steering reactive torque on the driver's feeling for a SBW vehicle. Outline of the SBW system and SBW vehicle are presented. Experiment results show that the steering reactive torque and steering gain have a big effect on driver's feeling, which was evaluated from the driver's mental and physical workload; and furthermore, optimum steering gain and steering reactive torque is dependant on driver's characteristics and driving task.

Place / Date:

Kanagawa, 10/02/2004

---

## 1. INTRODUCTION

The steering system is the primer interface between the driver and the vehicle, through which the driver inputs his intentions to control the vehicle direction, and from which the driver receives important information about the vehicle state of motion and road condition from the steering torque / 'steering feeling'. Consequently, the steering system characteristic has a great effect on the driver's feeling, and vehicle response towards driver's input.

Nevertheless, present steering system characteristics are usually designed as a compromise for various driving situations, and all aspects of drivers. In the future, Intelligent Transport Systems (ITS) and Advance Driver Assistance Systems demands the steering systems to have an adaptive functionality, whereby the steering system characteristics can be adjusted actively/appropriately according to driving situations, driver's needs and preferences, vehicle inherent characteristics, and environmental and traffic conditions, in order to minimize driver's workload, and at the same time, maintain driver's good feeling during driving.

Steer-By-Wire (SBW) steering system has been developed to achieve the above requirement, by eliminating the mechanical linkage between the steering wheel and the steering gear as like in a conventional steering system [1]. Hence, it is possible to define freely the relation between the tire steer angle with the driver's input (steering gain), as well as the steering torque with the driver's input, respectively, and thus, to change the steering system characteristics.

However, with such extensive degree of freedom of the design concept / control strategy for the steering system characteristics, it is important first, to understand the driver's feeling about steering gain and steering torque in an actual SBW vehicle, which is the objective of this paper. Ultimately, we wish to find out what is the optimum steering gain and steering torque for the individual driver, for a particular driving task.

## 2. OUTLINE OF SBW VEHICLE

For the purpose of the above study, the authors reconstructed an existing vehicle into a vehicle equipped with SBW systems.

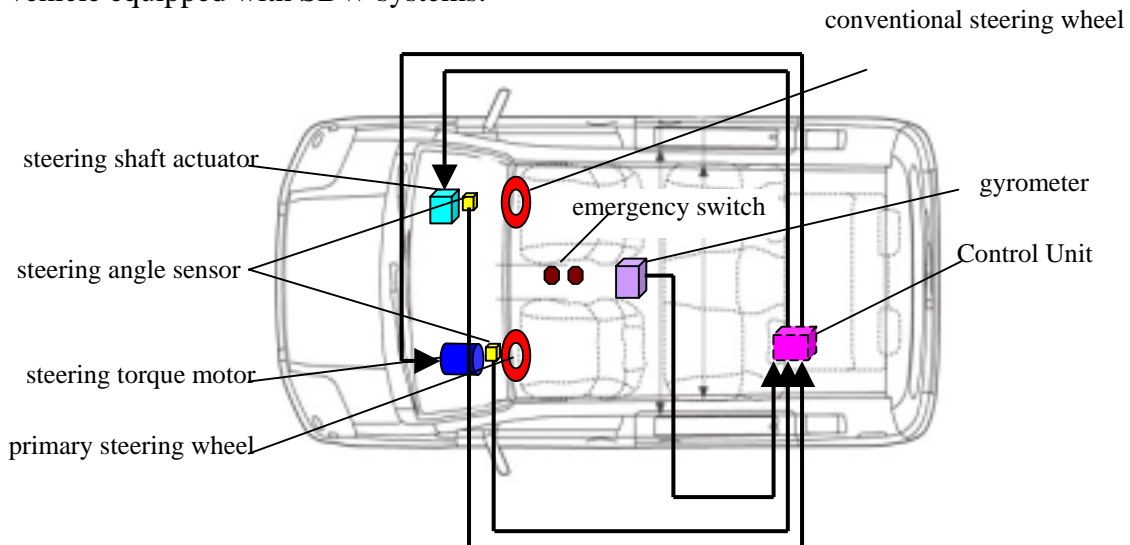


Figure 1: SBW vehicle configuration

The vehicle has a new steering wheel which is disconnected from the front wheels. The driver's steer input to the steering wheel is detected by a steering wheel sensor, while vehicle motion states are measured by the gyrometer, comprising of yaw rate sensor and lateral acceleration sensor. In addition, another rotation angle sensor (potentiometer) detects the steering column shaft turning angle. This information are transferred to the control unit (MicroAutoBox), which uses this to calculate the output steering angle and steering torque, based on the defined control algorithm.

An output steering angle signal is sent from the control unit to a motor actuator (step motor), attached to the conventional steering column shaft, which is connected to the steering rack and front tire by mechanical linkage, to control the front tire steer angle. Thus, by changing the steering column shaft rotation, in relation to driver's steer input, it is possible to change the overall steering gear ratio for the SBW vehicle.

A steering torque motor (servo motor), which is attached directly behind the steering wheel, generates the steering torque to the driver.

Two emergency switches that cut off power supply to the steering column shaft motor and steering torque motor are used in emergency situations to return the steering system to the conventional type, which enables the driver to take over a full control of the vehicle by using the conventional steering system.

### 3. OUTLINE OF TEST

In this paper, steering gain is defined as the amount of steering column shaft rotation in relation to the driver's steer angle. As a preliminary study, we set steering column shaft rotation as proportional to the driver's steer angle. Steering torque,  $T_q$ , is set proportional to driver's steer angle too, as well as proportional to vehicle yaw rate and lateral acceleration.

$$\delta_h' = G * \delta_h \quad (1) \quad T_q = K2 * r \quad (3)$$

$$T_q = K1 * \delta_h \quad (2) \quad T_q = K3 * a_y \quad (4)$$

where

- $\delta_h$  : driver's input steer angle [deg]
- $\delta_h'$  : steering column shaft rotation angle [deg]
- $T_q$  : steering torque [Nm]
- $r$  : vehicle yaw rate [deg/sec]
- $a_y$  : vehicle lateral acceleration [G]

Driver's feeling is investigated for two different steering gains, and various steering torque gradients and types of steering torque.

MODES	G=1	G=2
K1=0	Mode 1(M1)	Mode 1(m1)
K1=0.05	Mode 2(M2)	Mode 2(m2)
K1=0.10	Mode 3(M3)	Mode 3(m3)
K1=0.15	Mode 4(M4)	Mode 4(m4)
K2=0.2	Mode 5(M5)	Mode 5(m5)
K3=14	Mode 6(M6)	Mode 6(m6)

Figure 2: Modes of test

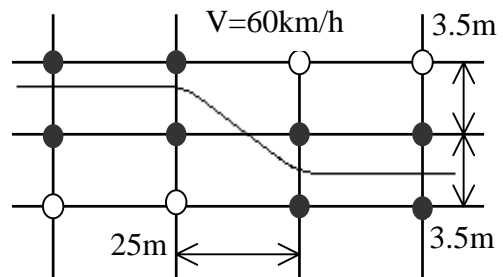


Figure 3: Lane change task

A single lane change task with vehicle velocity at constant, 60km/h is executed, and two young drivers were taken as the test subjects. Driver's input steer angle, steering column shaft rotation angle, steering torque, and vehicle motion i.e. yaw rate and lateral acceleration, are recorded. In addition, the drivers are asked to give their subjective feeling about the steering gain and steering torque after each test running.

#### 4. TEST RESULTS

Based on the driver's comments and the experimental results, obtained from various test modes, the author assumes that the effect of steering gain and steering torque on the driver's feeling can be described by using some objective measurement parameters, which will be explained in the following sections. These measurement parameters indicate the driver's physical and mental workload, which is believed to closely relate to the driver's feeling.

##### 4.1 Effect of Steering torque

In understanding the effect of steering torque to the driver's feeling, the author investigated on the steering torque magnitude, and the steering torque delay to the driver's steer input, and found that driver's good feeling in this lane change task greatly depends on this two factors. Here, the magnitude of steering torque,  $T_q$ , is related to the driver's physical effort when turning the steering wheel, and its optimum value depends on individual physical capability. Consequently, the magnitude of steering torque that is accepted as 'good', are different for the two different drivers. The magnitude of steering torque is expressed by the following index.

$$J1 = \int_{t_0}^{t_f} T_q^2 dt \quad (5)$$

Figure 4 shows the magnitude of  $T_q$ , J1 for all the test modes, and the "optimum magnitude of  $T_q$ ", as commented by driver 1.

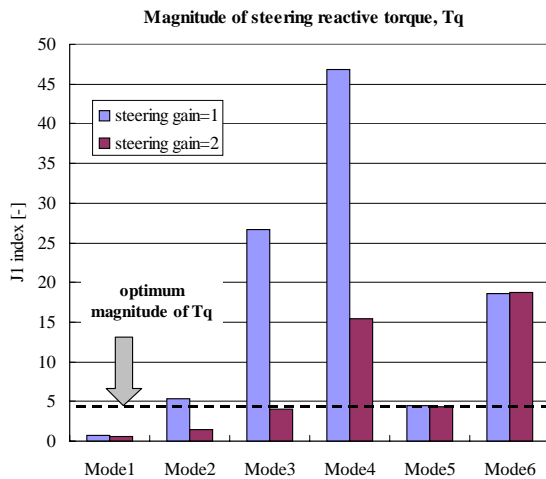


Figure 4: magnitude of  $T_q$

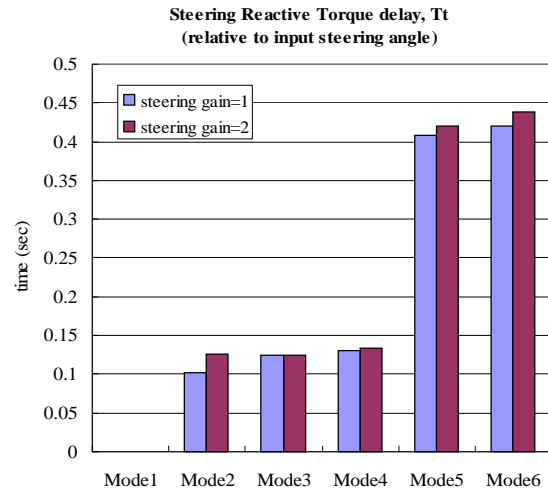


Figure 5: delay of  $T_q$

Next, the steering torque delay to driver's steer input is related to the driver's mental workload, because the driver has to advance his steering torque applied to the steering wheel (driver's steering torque) when giving a steer angle at the steering wheel, to compensate the steering torque delay. When  $T_q$  delay is small, subjective assessments

by both drivers are: easy-to-handle, easy-to-stabilize the vehicle after lane change, and a ‘quick’ feeling about the vehicle response. Figure 5 shows the steering torque delay,  $T_t$ , for all the test modes. Steering torques proportional to vehicle yaw rate and lateral acceleration as response-feedback information about the vehicle state of motion through the steering wheel are investigated too (Mode 5 and 6). However, it is found that due to the delay of yaw rate and lateral acceleration, drivers found these types of steering torque to be unsuitable for medium-speed lane change.

From the two discussions above, ‘Driver’s Good Feeling Graph’ is plotted, showing the optimum magnitude of steering torque,  $J_1$ , and the optimum delay of steering torque to driver’s input,  $T_t$ , rated by the two drivers, respectively.

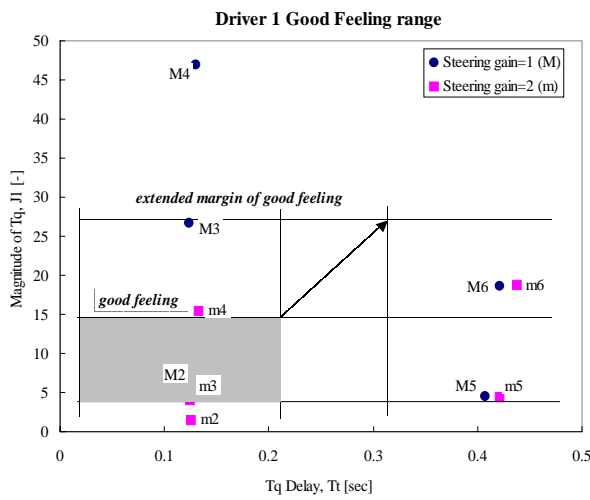


Figure 6: Driver 1 Good Feeling Graph

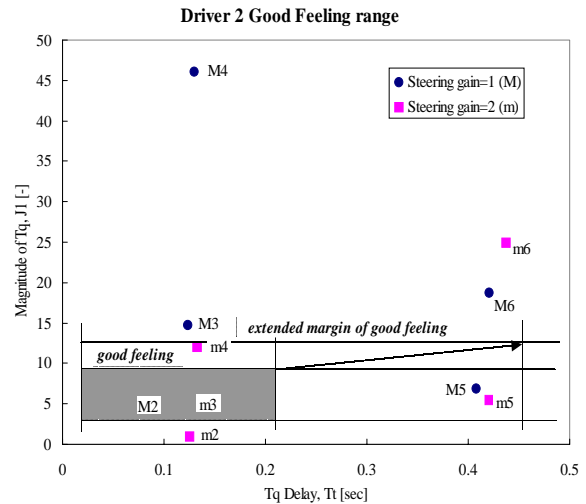


Figure 7: Driver 2 Good Feeling Graph

It is seen from the “extended margin of good feeling”, compared to the “good feeling range”, in the two graphs, that driver 1 is more sensitive to the steering torque delay, while driver 2 is more sensitive to the magnitude of steering torque. In other words, driver 1 can accommodate larger magnitude of steering torque than driver 2; while on the other hand, driver 2 can accommodate larger delay of steering torque than driver 1. This somehow agrees with the fact that driver 1 is physically fitter than driver 2, while on the other hand, driver 2 has a driving manner/habit characterized by more steering corrections, which represent adaptation to steering system delay and vehicle steering response delay.

#### 4.2 Effect of Steering Gain

For this particular lane change task, both drivers rating for steering gain of 2 (overall steering gear ratio of 8) is better than steering gain of 1 (overall steering gear ratio of 16). This is much contributed by the reduction of the amount of driver’s steer input required to complete the lane change task, which reduces the driver’s physical effort. In addition, the author also looks at the driver’s steer velocity, which is another parameter that represents driver’s physical effort in turning the steering wheel. The amount of steer angle, and amount of steer velocity, are represented by the following indexes, respectively.

$$J2 = \int_{t_0}^{t_f} \delta_h^2 dt \quad (6)$$

$$J3 = \int_{t_0}^{t_f} |\dot{\delta}_h| dt \quad (7)$$

Figure 8 and 9 shows the amount of steer angle, J2, and amount of steer velocity, J3, for all the test modes, for the case of driver 1, and it is clear that the driver's physical effort had been reduced with smaller overall steering gear ratio.

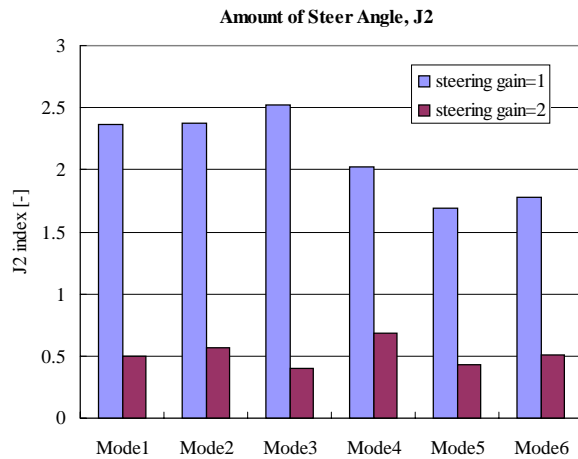


Figure 8: amount of steer angle

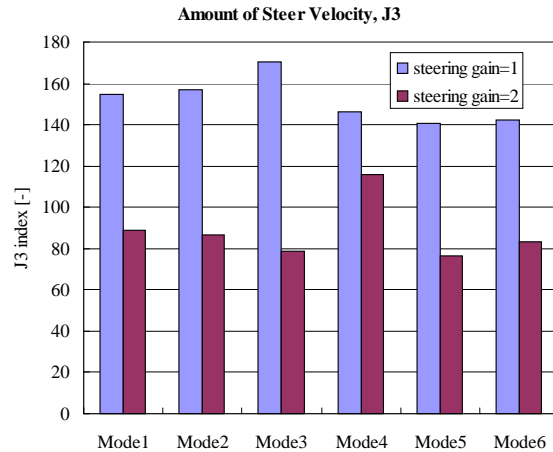


Figure 9: amount of steer velocity

However, driver's good rating for steering gain of 2 is under the condition that Tq proportional gain to steer angle, K1, is doubled in accordance to the decrement of overall steering gear ratio from 16 to 8. This is because although the steering wheel angle needed becomes half of the conventional vehicle, it is found that the amount of Tq needed by the driver to complete the lane change task remains same amount as for the conventional vehicle. In other words too, the steering torque should correspond to the vehicle motion / output steering angle, instead of the driver's steer input.

As additional study of the effect of steering gain, the same lane change task with steering gain of 3 (overall steering gear ratio of 5.33) and steering gain of 4 (overall steering gear ratio of 4) is executed. However, both drivers commented that the steering system is too sensitive, and such high steering gain is unsuitable for this lane change at medium speed. Then, an intentional course reflecting normal driving condition at low speed, large steering angle is arranged, and a trial running with vehicle velocity at less than 25km/h, and steering gain of 4, was executed. Both drivers could easily adapt to the high steering gain, after getting familiarized with the SBW vehicle, and evaluates that steering effort had been greatly reduced, particularly during the returning of steering wheel to neutral position after large cornering.

## 5. CONCLUSIONS

The effect of steering torque and steering gain, respectively, on the driver's feeling, was investigated in this study by using some objective measurement parameters, which represent the driver's physical and mental effort. The results are summarized as below:

1. The driver's good feeling is influenced by two factors, namely the steering torque magnitude and steering torque delay to driver's steer input. Firstly, steering torque

magnitude is related to driver's physical effort, and its optimum value depends on driver's individual physical capability. Secondly, steering torque delay is related to driver's mental effort, where minimum delay is desirable by both drivers. Driver's driving manner is considered to have an influence on driver's ability to adapt to larger steering torque delay.

2. Higher steering gain (smaller overall steering gear ratio) reduces the driver's physical effort in terms of amount of steer angle and steer velocity required to complete the lane change task, and thus contributes to driver's ease of driving.
3. It is assumed that the amount of steering torque desired by the driver remains the same for a particular driving task, and hence, when steering gain is doubled, the steering torque proportional gain,  $K_1$  has to be doubled accordingly too, indicating that there is a close relationship between the steering gain and steering torque proportional gain.

The current study could be extended to different category of driver also, such as aged driver, to investigate on the optimum range of magnitude of  $T_q$ , delay of  $T_q$ , and ideal steering gain, in accordance to vehicle speed for good feeling and minimum physical or mental effort.

## 6. ACKNOWLEDGEMENTS

This project is part of the Key Technology Research Promotion Program "Development of Advanced Assistance System Adapted to Elderly Drivers", funded by the New Energy and Industrial Technology Development Organization (NEDO) of Japanese Government. The author also wishes to thank the members of Abe Laboratory for their contribution in the construction of the SBW vehicle.

## 7. REFERENCES

- (1) M.Segawa, S.Kimura, T.Kada, S.Nakano, "A Study of the Relationship between Vehicle Behavior and Steering Wheel Torque on Steer By Wire Vehicles", Extensive Summaries of 18<sup>th</sup> IAVSD Symposium on Dynamics Of Vehicles on Roads and Tracks, pp67-69, 2003.