Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnline CONFERENCE PAPER ARCHIVE

IFAC-PapersOnLine 49-3 (2016) 129–134

Optimization of Parameters in the Hysteresis-based Steering Feel Model for Steer-by-Wire Systems ⋆

Ahmet KIRLI * **M. Selçuk ARSLAN** **

* *Department of Mechatronics Engineering, Yildiz Technical University, Istanbul, 34349 Turkey (akirli@yildiz.edu.tr)*
** *Department of Mechatronics Engineering, Yildiz Technical University, Istanbul, 34349 Turkey (e-mail: msarslan@yildiz.edu.tr)*

Abstract: In rubber-wheeled vehicles, mechanical connection between steering wheel and front wheels provides steering related feedback to the driver. The torque fed back to the driver through the steering linkages and steering wheel, which is called steering feel, helps the driver in controlling the vehicle. The torque feedback is reproduced via artificial methods in steer-by-wire systems due to the lack of mechanical connection. Different approaches have been reported to describe the steering feel for steer-by-wire systems. A recent study reports a steering feel design based on Bouc-Wen hysteresis model. This model describes the steering feel through five constant coefficients, longitudinal velocity and steering wheel angle. In this work, in order to minimize the physical workload and the lateral acceleration under the consideration of handling performance, optimization of those five parameters has been studied. A 2-DOF bicycle model based on Magic tyre formula has been used for simulations. The effect of each parameter on steering feel has been identified for the optimization study. A driver model with a controller has been designed to perform comparable and repeatable tests. Weave and double lane change tests have been performed in order to demonstrate and quantify the optimization of the hysteresis model.

Keywords: steering feel, steer-by-wire, hysteresis, physical workload, optimization

1. INTRODUCTION

In classical road vehicles, the steering action is performed through the mechanical link between the front wheels and the steering wheel. When the front wheels are steered, a reaction torque, which is mainly based on the self-aligning torque(SAT), occurs, and the driver experiences the steering feel as a tactile feedback through steering wheel. Since the steering feel has a significant effect on the handling quality, it is stated as an essential feedback to the driver Segel (1964); Kim and Cole (2011).

The effect of the steering torque feedback on the driver is not understood well since it is both objective and subjective. Although there are studies in the literature in order to quantify the steering feel Katzourakis et al. (2012); Dang et al. (2014), they are still in their infancy.

In steer-by-wire(SBW) systems, elimination of the steering column results in the loss of mechanical connection between the front road wheels and steering wheel. A force-feedback system becomes indispensable for providing a steering feel to the driver. This feel is provided through an electrical motor attached to the steering wheel.

Most of the studies in the literature mainly or partially use estimated SAT information to generate the conventional steering feel, Oh et al. (2004); Salaani et al. (2002); Balachandran and Gerdes (2014). Estimation of SAT brings some difficulties and complexity. Also, it is not suitable for lower velocities and when the vehicle is stationary. An additional approach seems to be needed to reproduce the steering feel in such cases, when the model based on the SAT is not applicable. Additionally feeding the SAT back to the driver during the automatic control of road wheels would have a disturbing effect.

The steering feel, which is essentially the steering wheel's torque feedback, had to be designed so that it should reflect the maneuvering dynamics correctly. In the design of steering feel, the reflection of road wheels and road interaction to the driver is of crucial importance. In provision of this feedback, the steering torque feedback in the steering wheel system can be generated based on either the force signal from load cells attached to the rack, or the mathematical model designed to produce the steering feel which is indispensably dependent on the estimation of tire parameters. When the cost, replacement, and calibrations of the load cell are taken into account, it is understood that the estimation based model would be more suitable, Pfeffer et al. (2008); Balachandran and Gerdes (2014).

The experimental studies in the literature show that a lag characterizes the relation between the steering wheel angle and the torque reflected to the driver in the classical road vehicles. It is well-known that the vehicle dynamics is

⋆ This research is principally funded by The European Union, Marie Curie Actions-Support for training and career development of researcher. [Project ID: PCIG09-GA-2011-294231 - SteeringFeelSBW]

10.1016/j.ifacol.2016.07.022

dominated by tire dynamics. Mainly the relaxation length in a tire is responsible for the lag, which delays the tire side forces, Heydinger et al. (1994). A recent work, Arslan (2015), has reported a steering feel model based on the hysteresis phenomenon appearing in the steering action. In our study, we use this steering feel model, which is designed by using the Bouc-Wen hysteresis model.

There is still no general and sufficient model for designing the steering feel in the literature. This is still an ongoing research phenomenon, yet we introduce a new angle in terms of designing the steering feel which pay attention to physical workload.

Although there are a few works mentioning physical workload, Tajima et al. (1999), none of them considers this issue as a design parameter. Besides, there is no general mathematical definition of the physical workload. In this study, physical workload is defined with a new mathematical model and it is considered as a design parameter for creating the optimum steering feel through the hysteresis-based model approach.

This design approach aims at the minimization of the physical workload while satisfying the safety and sufficient handling performance. Another important criterion in this approach is the lateral acceleration. In order to provide safe and comfortable driving, the lateral acceleration should be kept to a minimum, Kirli and Arslan (2016).

In brief, this study introduces an optimum steering feel design based on a hysteresis model, in which the driving quality is increased and, at the same time, the physical workload is decreased. To test the performance of the steering feel model, the simulation approach has been preferred. Magic tyre model is used, Pacejka and Bakker (1993), for a bicycle model, Rajamani (2011), because of their simplicity and wide acceptance. Two case studies based on standard test procedures have been presented: The weave test and double lane-change test. The performance of a vehicle with optimized hysteresis-based steering feel model has been compared with both the same vehicle with default hysteresis-based steering feel and a SAT-based model. The reason of selecting the SAT-based model is that it is the main factor in generation of the steering feel in conventional vehicles. Thus, a realistic comparison could have been done.

The remainder of this paper is organized as follows: Section 2 introduces the hysteresis-based steering feel model, the vehicle dynamics, the simulation environment including the controller and the driver model. Section 3 demonstrates the optimization. Section 4 discusses the results, summarizes this work and Section 5 gives the conclusions.

2. SIMULATION ENVIRONMENT AND DYNAMICS

The dynamics of all elements in of the entire simulation model are described in this section. There are two main parts consisting of vehicle dynamics and steering feel model. The simulation model has three main parts including a global coordinate transformation, driving model and a classical PD controller couple representing a simple mechanical driver dynamics, Fig. 1. Note that the torque feedback applied to the steering wheel, T_{sw}, which is essentially the steering feel generated by the hysteresis-based model, is opposite to the torque of controller, T_c. In Fig. 1, X and Y are the coordinates of the vehicle with respect to Earth-fixed reference system and θ is the steering wheel input angle.

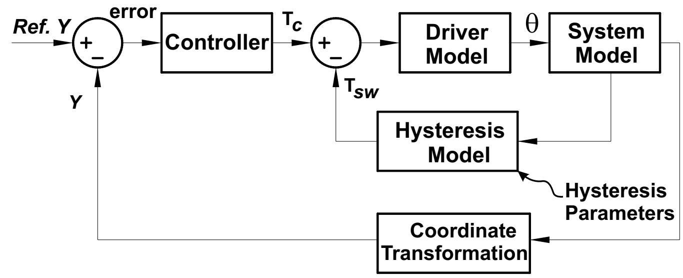

Fig. 1. Main components of the simulation environment

2.1 The tyre model

A well known and widely used semi-empirical tyre model to calculate the tyre forces and moments for use in vehicle dynamics is the Magic Formula. Once the tyre forces are obtained, a two degree of freedom dynamic model for lateral vehicle motion is developed by using bicycle model. The nominal values of a passenger car are used for vehicle dynamics. The parameters of the vehicle are taken from a large front wheel drive saloon car, Genta (1996).

A simulation model has been created through MATLAB/ Simulink® environment. For details, the reader is referred to the cited references.

2.2 Self-aligning torque

The steering feel occurs as a result of the tire-road interaction during the steering of the front wheels. The self-aligning torque plays the main role in generation of the steering feel in conventional vehicles. To calculate the pneumatic trail and SAT the magic tyre model is used with the empirical parameters given in Wong (2001).

In order to perform a realistic comparison, SAT is crucial. The SAT has been used as a reference for three purposes: The first is to help to understand the steering feel characteristic of a classical vehicle. The second is to use in determining the default values of the hysteresis parameters. The last is to clarify and identify the performance of the optimized hysteresis-based model.

2.3 Hysteresis-based steering feel model

Bouc-Wen model of hysteresis introduced by Bouc, (Bouc (1971)) and generalized by Wen, (Wen (1976)). This model describes the output restoring force to the input displacement in the form of a first order nonlinear differential equation. The nonlinear hysteretic behavior of a physical system can be described as a map $x(t) \mapsto \Phi(t)$, where x and $\Phi(x)$ represents the time histories of an input and hysteretic output, respectively. It is known that for any bounded input $x(t)$, the output $\Phi(x)(t)$ is bounded Ikhouane and Rodellar (2007). This behavior can be described by the Bouc-Wen hysteresis model: