AUTOMATIC STEERING CONTROL MECHANISM USING SENSOR

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بسم الله الرحمن الرحيم

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Bachelor of Science in Technical vocational and education Education in Mechanical Engineering

CANDIDATES DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Signature of the Candidate **Signature of the Candidate**

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Reality is, we came here as boys, but the little time we spent with

You lots made us the men we are today. We doubt that we will

Ever be able to convey our appreciations fully, but we owe you our eternal gratitude.

Abstract

For use in an agricultural machine which is automatically steered by sensing along a row of plants, a component of the automatic steering system, namely, a comparator system is disclosed herein which utilizes hydraulic signals from independent sensors and mechanically

Compares such signals with each other and with a mechanical feedback responsive to the degree of angularity of the steered wheels of the vehicle. The net result of the combination and construction of the comparator system is to provide automatic steering control for a small variation of steering of left and right steering courses, for example 2 to 5 degrees, wherein any large amount of deflection of the
steering wheels that may be caused by the vehicle operator taking

Over the steering function will not affect the automatic operation of the comparator mechanism or will the comparator mechanism have any response thereto? Further the hydraulic system of the comparator sensors which "feel" the presence of corn stalks or vines ahead of the vehicle is hydraulically isolated from the hydraulic circuitry of the

comparator interior. The invention is susceptible for use for directory guidance by a single row of plants, for example corn stalks, or by guidance between directories, e.g., parallel rows of plants. Due to the fact that two sensors are utilized which function independently of each

Other should interruption of the directory, for example, a row of corn stalks, occur due to a cross path, there would be no sudden sharp steering deflection and the vehicle would continue in straight steering.

CHAPTER 1-INTRODUCTION

The steering wheel of a car is one of those instruments which we pretty much take for granted. We mean, who ever heard of a car with no steering wheel? When buying a new car for instance, we bring hell upon the head of the sales person, asking all kinds of more or less ridiculous questions about the fabric on the seats, the number of bolts holding the wheels in place or the composition of the paint. In very rare cases, we think to ask about the steering wheel.

Some of us even think the steering wheel magically came to be at the same time the car did. That it was somehow already in the mind of the inventor as the perfect tool to make the new contraption work. That's not entirely true. The steering wheel did not came to be at the same time with the car, but was adopted later, as it became obvious its shape is perfect for the task.

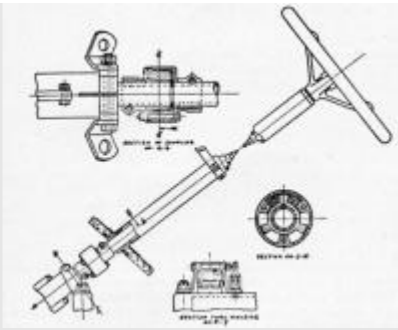
You must take into account that at the turn of the 19th century, when the idea of the automobile germinated in the minds of the time's inventors, there was really a single man-made machine the man himself controlled: boats.

There was no way to steer a train, as its tracks guided it from point A to point B without human input. Turning a carriage only meant pulling the harness left or right, depending on your intentions, so there was no need for an additional mechanical device to be created.

All of the above meant that the car's inventors had really one source for inspiration when trying to figure out how to steer a car: boats. Boats used human activated rudders, controlled by means of tillers, to turn, so the idea appealed to the car's creators.

By 1894 however, the use of a tiller to steer a car became more and more ineffective. Taking inspiration from the same nautical industry, car builders began replacing the tillers with ship-inspired helms. Simpler and smaller than their nautical counterparts, the steering wheels in the car made their mark during the Paris-Rouen race, when the Panhard model driven by Alfred Vacheron was first recorded using a steering wheel to turn. The ease of operation shown in the 1894 race meant that by 1898, all Panhard et Levassor cars came equipped as standard with steering wheels. The principle quickly caught on and similar systems sparked across the world. In Britain, Charles Stewart Rolls bought a Panhard from France and implemented the steering wheel into his designs. By 1899, the steering wheel fever expanded to the US, where Packard introduced the steering wheel on one of its models. By the time the Model T arrived, the steering wheel was an essential part of the car.

After that moment, the steering wheel stuck with the car, with its most common shape, that of a circle, unchanged for more than a century now. What did (and still does) change however is the purpose the steering wheel serves. As humanity crawls its way through the 21th century, the steering wheel is quickly leaving behind its established role of "helm of the car" and becomes more and more of a command hub for the entire vehicle. But let's take it one step at the time. **POWER STEERING**



Davis hydraulic power system drawing

For decades, the steering wheel remained nothing more than a wooden circle, mounted inside the car and through which the driver controlled the directional movement of the vehicle. It had and it served no other purpose. As you might imagine, steering with early wheels was not an easy task, as the whole procedure was done mechanically: the driver pulled the steering wheel to the left or right. Of course, the wheels resisted the commands, and the friction with the surface below made steering a difficult task at times, especially when the car was stationary. After the war, Chrysler began developing its own power steering, based on Davis' expired patents. The system was featured on the Chrysler Imperial and was named Hydraguide. Since competition is the driving force of the industry during peace time, GM made a deal with Davis for the system and by 1953, 1 million vehicles using it were built. The success was immense and instant: by 1956, one in four cars on the roads had power steering. By the next decade, 3.5 million power steering systems were sold.

Since Davis, several types of power steering systems have been developed. Depending on what is used to power the steering wheel, the systems can be hydraulic, as Davis', electro-hydraulic, electric and so on. Some manufacturers, like Citroen and AM General, patented their own technologies (DIRAVI and Servotronic, respectively).

Today, the ratio has turned against non-power-assisted vehicles. Yet, despite a new role for the steering wheel, that of making the driver's task easier, the steering wheel itself remained in design as simple as it got. The only added function was the introduction of the airbag in the 1970s.

STEERING WHEEL CONTROL CENTER

For decades, the only other role given to the steering wheel, besides controlling the direction of the car, was that of a platform for the horn activation switch. It was only in 1960 that some carmakers began fitting the cruise control operating switches onto the wheel. That was about it for the steering wheel until early 1990s, when the advancements in infotainment and in-car gadgetry really took off. The avalanche of buttons and switches needed to control the audio system, the car's computer and so on meant interior car designers would have a hard time cramming it all onto the center console. They needed space for the buttons and switches and, most of all, they needed buttons and switches to be within the reach of the driver.

Obviously, their attention turned to the steering wheel, roughly the single in-car component which satisfied both needs. As a result, steering wheels began their transformation from rudders to control centers. They grew in size, as more space was required to accommodate the controls and wires which go with them. They exploded in designs, as the various needs of the engineers and designers dictated the shape. And there's no telling where the steering wheel will end up in the future. The TSS (Torque Sensor Steering) was developed for vehicles with electric power steering EPS. The sensor measures the steering force applied by the driver and thus enables sensitive control of the electric steering support.The sensor is based on a contactless magnetic measuring principle. It consists of the Magnet Unit, the Flux-Tube Unit and the Sensor Unit. Its compactness guarantees high freedom of design. Due to the redundancy of the electronic components, the sensor meets all requirements of modern safety systems.

Steering sensor

The steering sensor is attached to the steering gearbox with a provided bracket and measures rotary motion of the output shaft. It has an industry standard wire harness connector

Steering wheel sensor

Fig: steering sensor

92-95 Honda Civic Driver Side Air Bag + Steering Wh

Deville 2000-05 Seville 00-04 New OE Steering Wheel Positio

Fig: Steering Speed Sensor

Dorman (OE Solutions) 905-513 Steering S

One New Steering Wheel Position Sensor (Dorman# 601-003)

Fig: One New Steering Wheel Position Sensor

Steering Torque Speed Sensor (Dorman 905-513)

Fig: Steering Torque Speed Sensor

[Steering Wheel Positioning Sensor - Fits 03-12 GM Models Truck & SUV]

Fig: Steering Wheel Positioning Sensor

[Steering Wheel Motion Sensor (Dorman #]

Fig: Steering Wheel Motion Sensor

[03-05 CROWN VICTORIA CONTROL SWITCHES, STEERING WHE]

Fig: VICTORIA CONTROL SWITCHES, STEERING WHEEL MOUNTED

CHAPTER -2 ***Advances in Steering Mechanisms.(First step to steer by wire)***

2.1 Introduction

Mainly focusing on electro-mechanical power steering

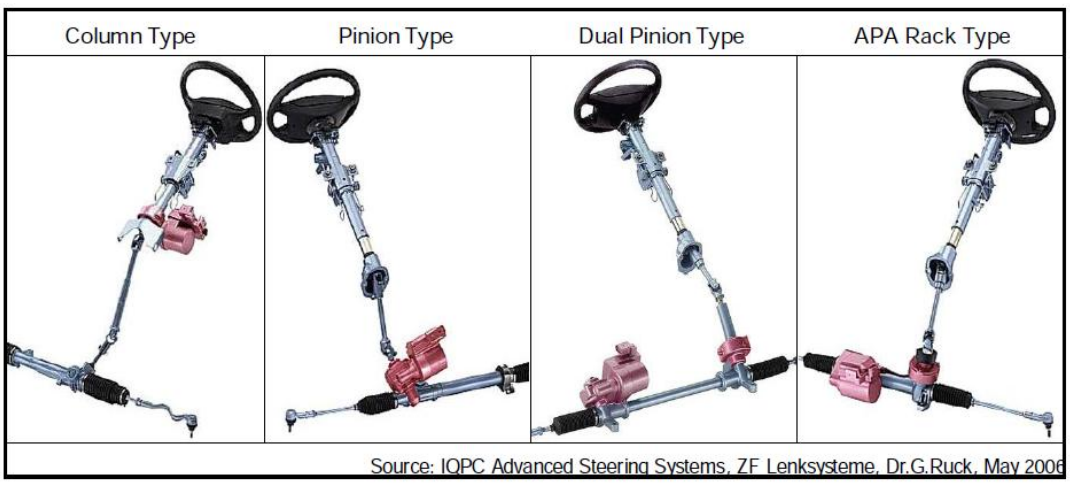
Requirements

- Should be very accurate and easy to handle
- Effort required to steer should be minimum
- Should provide directional stability
- Easy alteration of driving direction

Overview Of Electric Power Steering

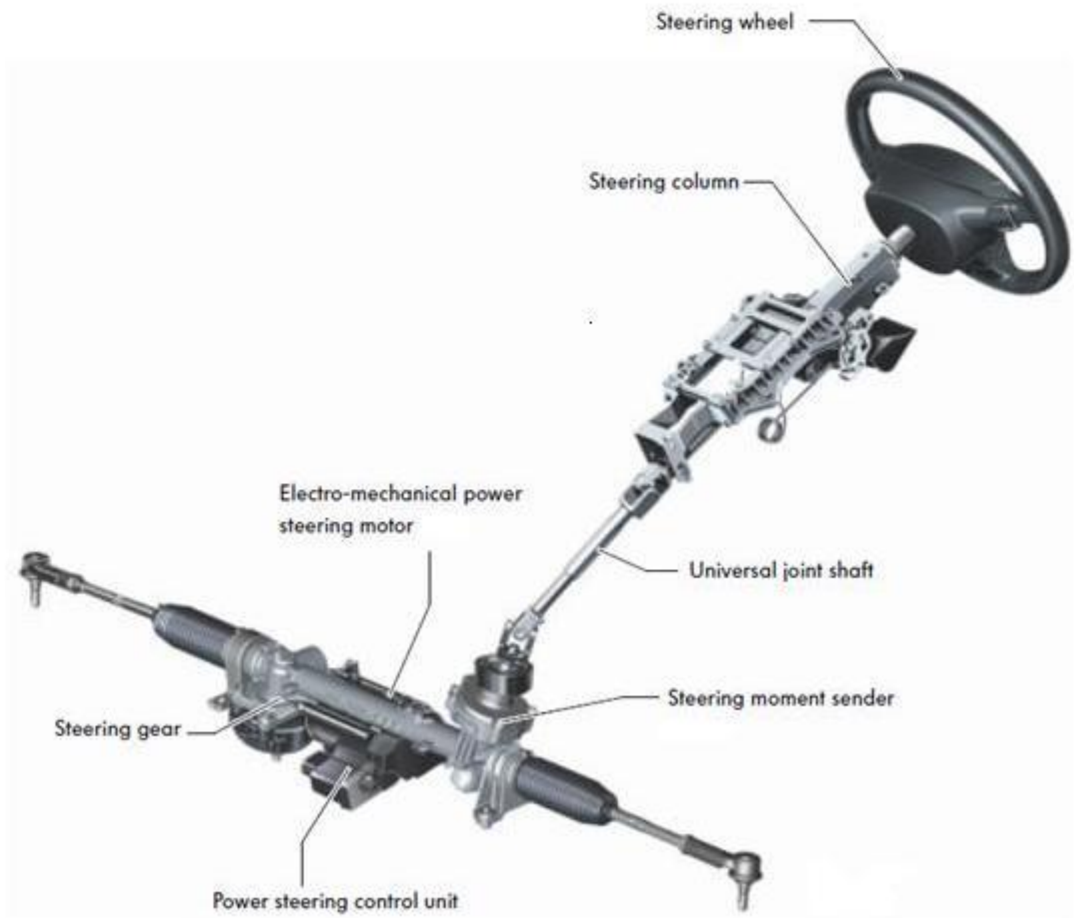
- No requirement for hydraulic assistance (Eliminating hydraulic oil)
- System provides assistance depending on the driving conditions
- Supports the “active return” function
- Easier for the driver to steer the vehicle in a straight line when the vehicle is being affected constantly by side winds or driven up or down hills
- Types Of Electric Power Steering
- 1 Column type EPS

- 2 Pinion type EPS
- 3 Dual pinion type EPS
- 4 Offset Ball Screw type EPS
- 5 Direct drive type EPS
- Types Of Electric Power Steering
- 1 Column type EPS
- 2 Pinion type EPS
- 3 Dual pinion type EPS
- 4 Offset Ball Screw type EPS
- 5 Direct drive type EPS

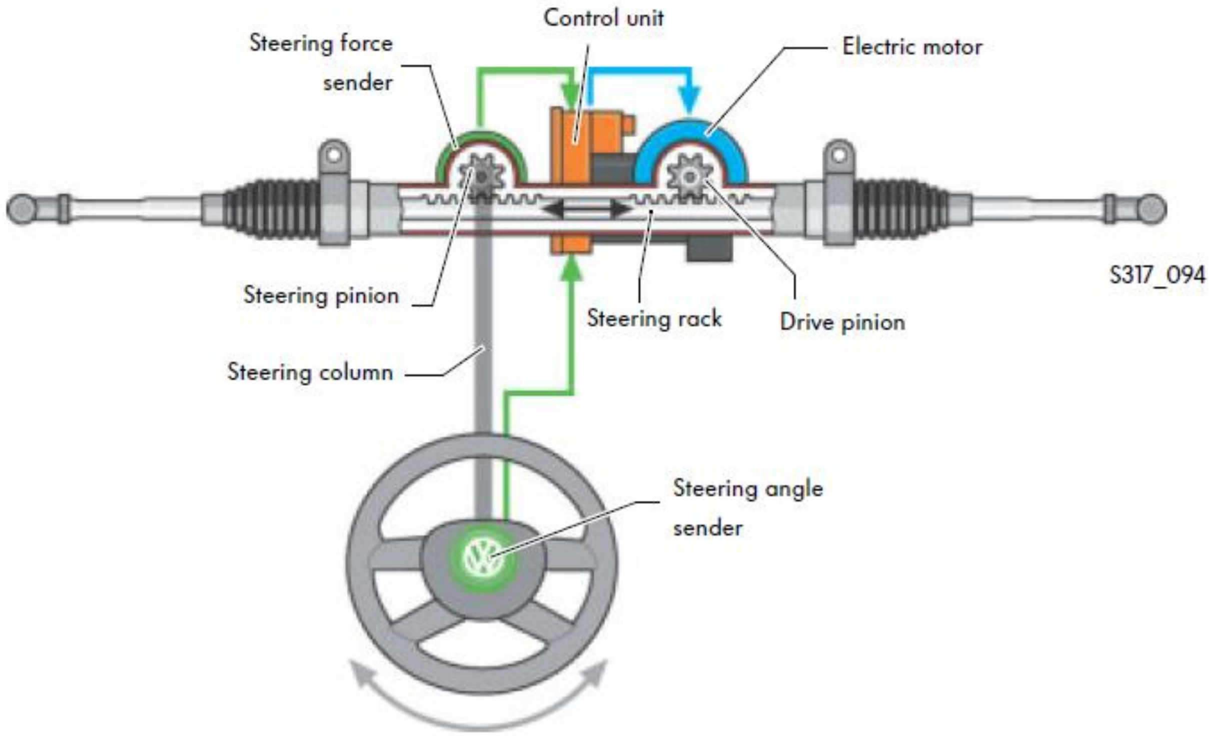


- System Overview
  The electro-mechanical power steering
  with dual pinion
- System components Of EPS
- Steering wheel
- Steering column switch with steering angle sensor
- Steering column
- Steering moment sensor(Torque sensor)

- Steering gear
- Electro-mechanical power steering motor
- Power steering control unit System Overview
  Actual View



Schematic View

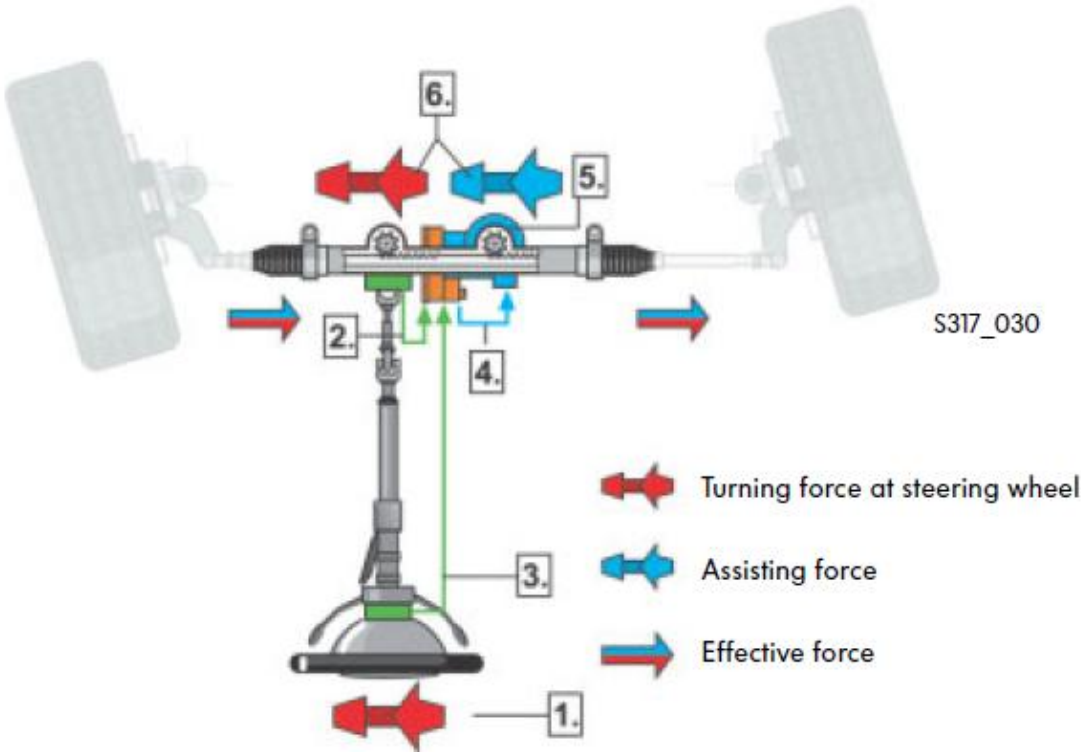


Disassembled view

Functioning

There are five general modes of operation of E

The steering function



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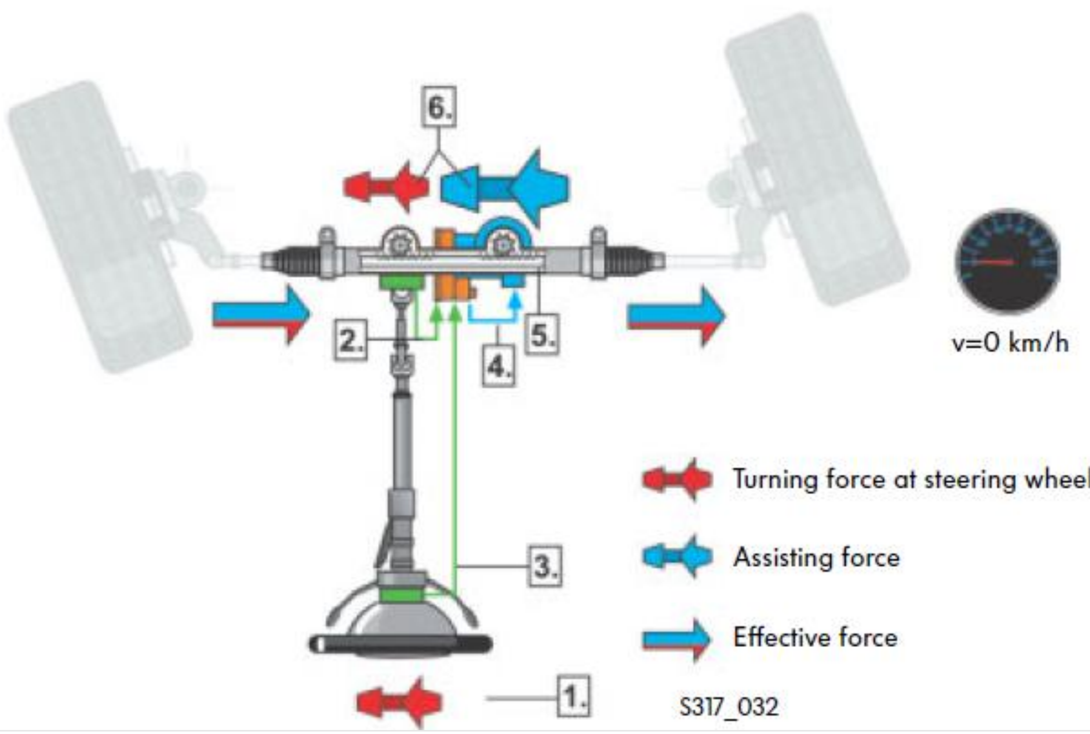
The steering function for parking manoeuvres



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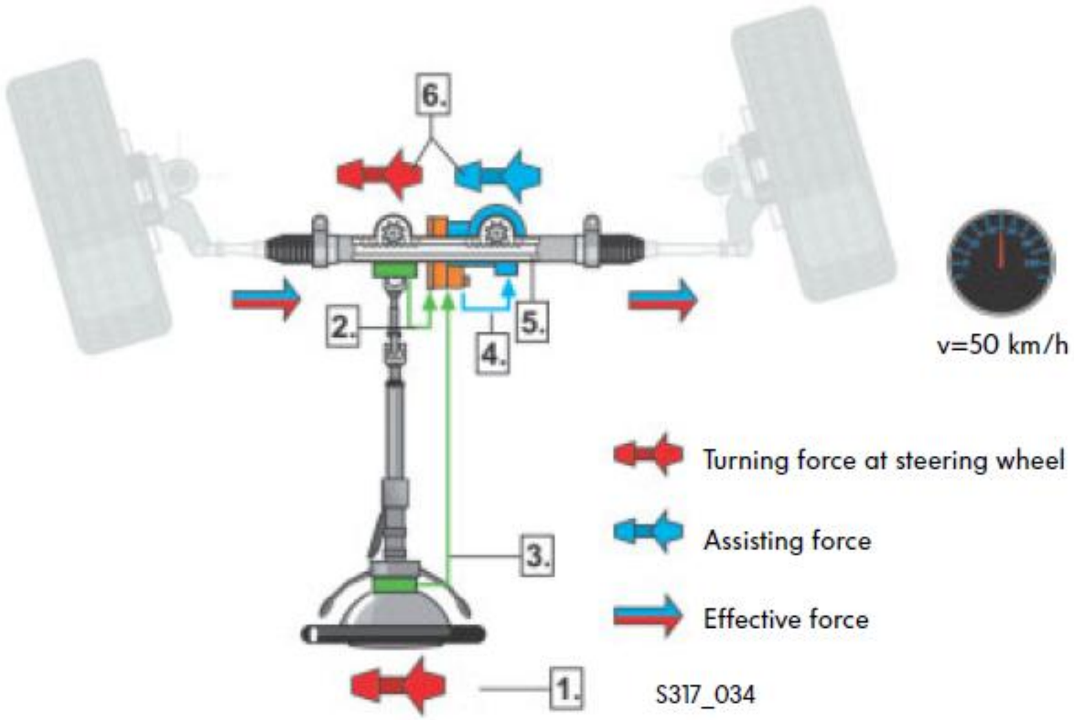
The steering function in urban areas



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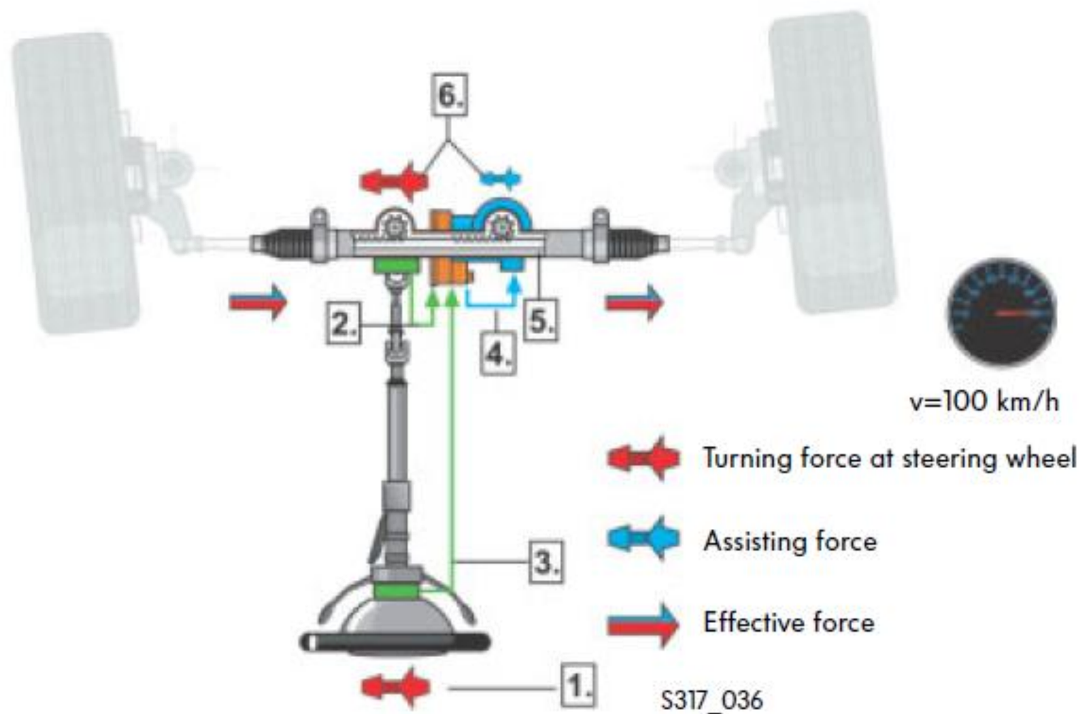
The steering function on motorways



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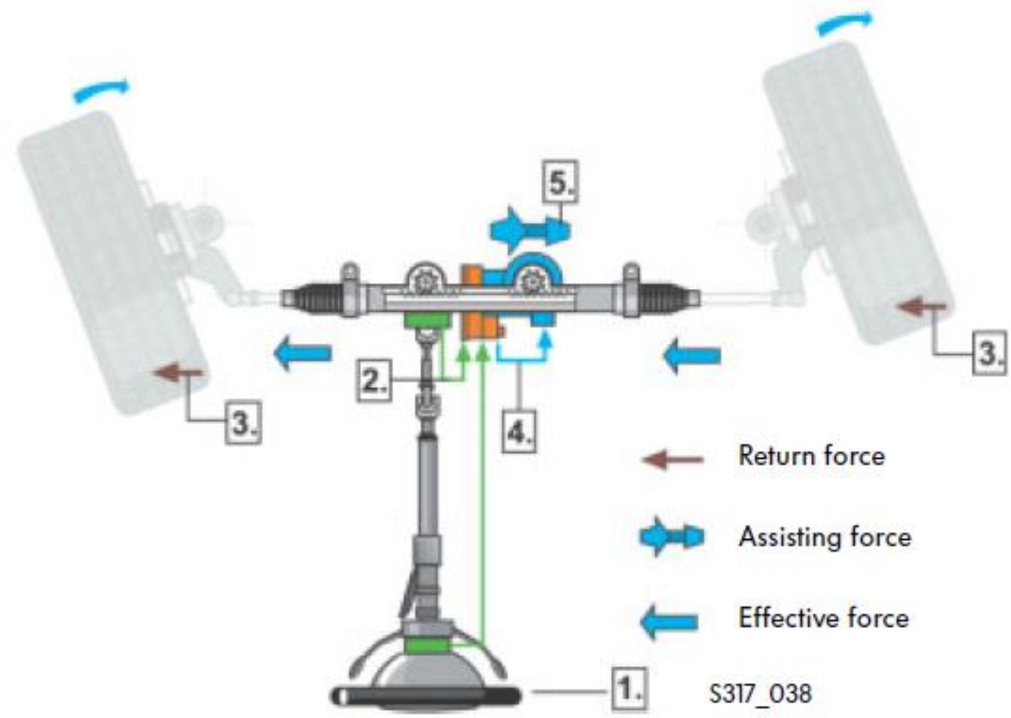
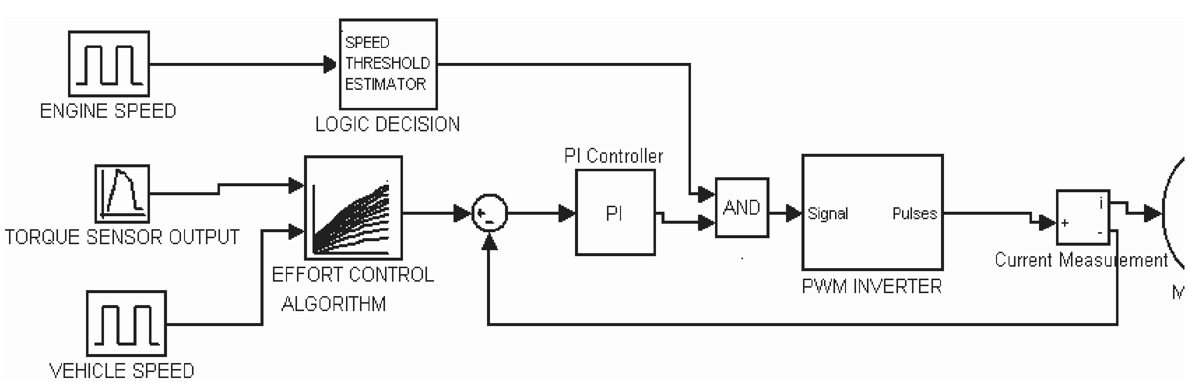
The active return function



<u>Control Strategies</u> Control architecture consists of two layers of control

- Effort level control (Torque Sensor)
- Assistance level control (Vehicle speed sensor)
- <u>Effort Level Control</u>
- Information like engine speed, and torque required are transmitted to control module, which determines the optimal degree of assistance the electric motor should apply
- 

Control algorithms.

Effort level control

During any 120 degree interval of phase current *I*, the instantaneous power (P) being converted from electrical to mechanical is

$P = \omega T_e = 2EI$

T_e = Electromagnetic torque

E = Induced EMF per phase.

$E = 2N_{ph}B_gLr\omega$, *per phase induced emf*

N_{ph} = Number of winding turns per phase

B_g = Rotor magnetic field density

L = Length of the rotor

r = Internal radius of rotor

Effort level control

Using the above expression the electromagnetic torque is given by,

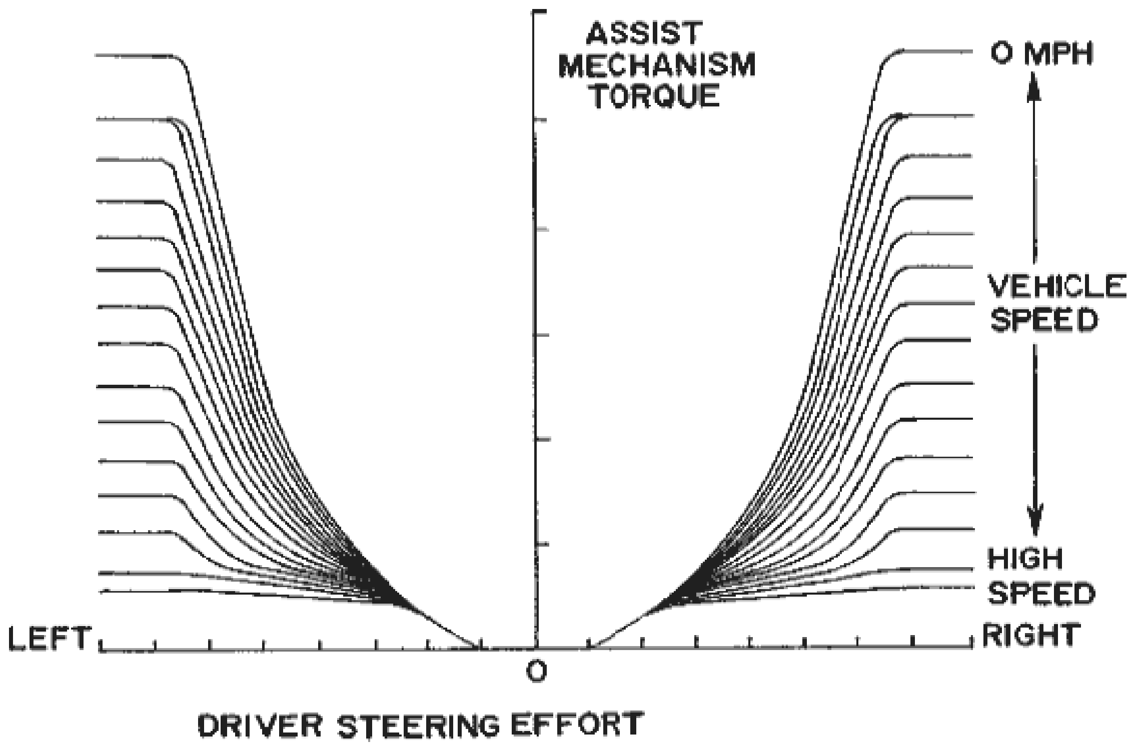
$T_e = 4N_{ph}B_gLrI = K\varphi I$

Where,

K = Torque constant

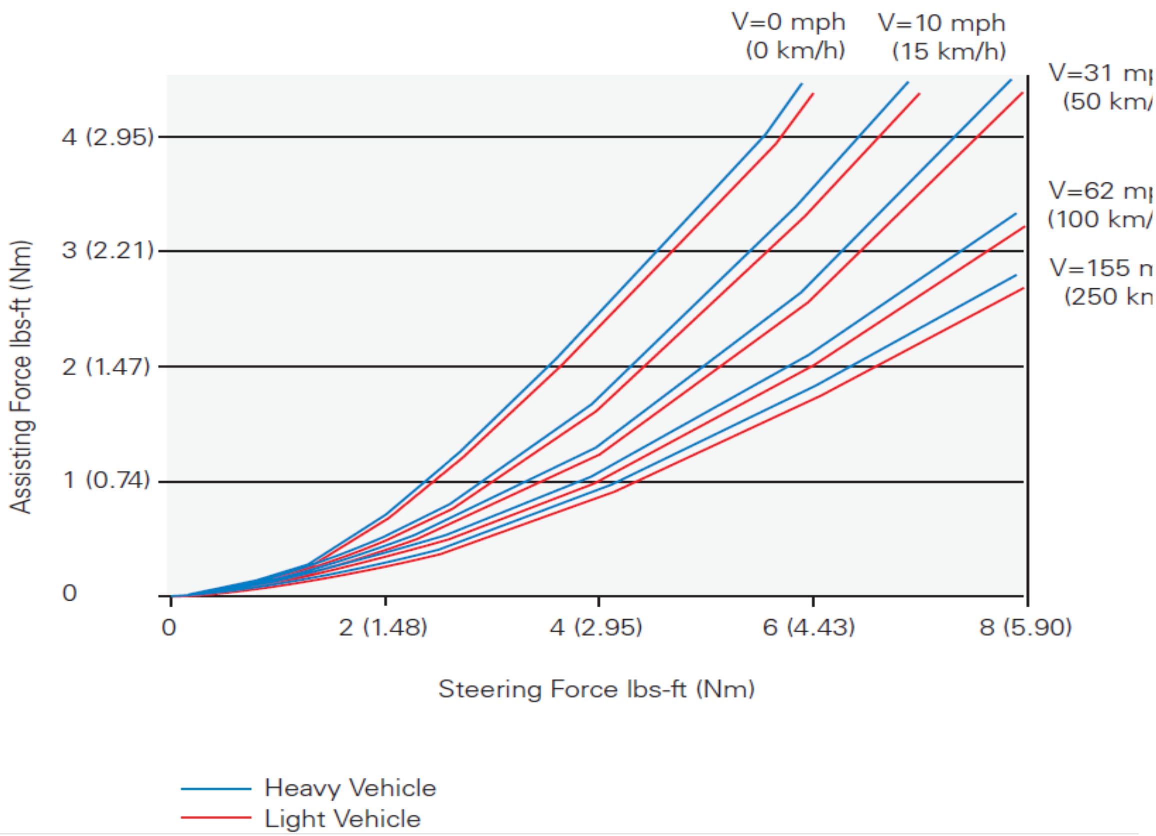
φ = Flux per pole pair *Assistance Level Control*

Figure shows the effort required to be produced by the motor for various vehicle speeds

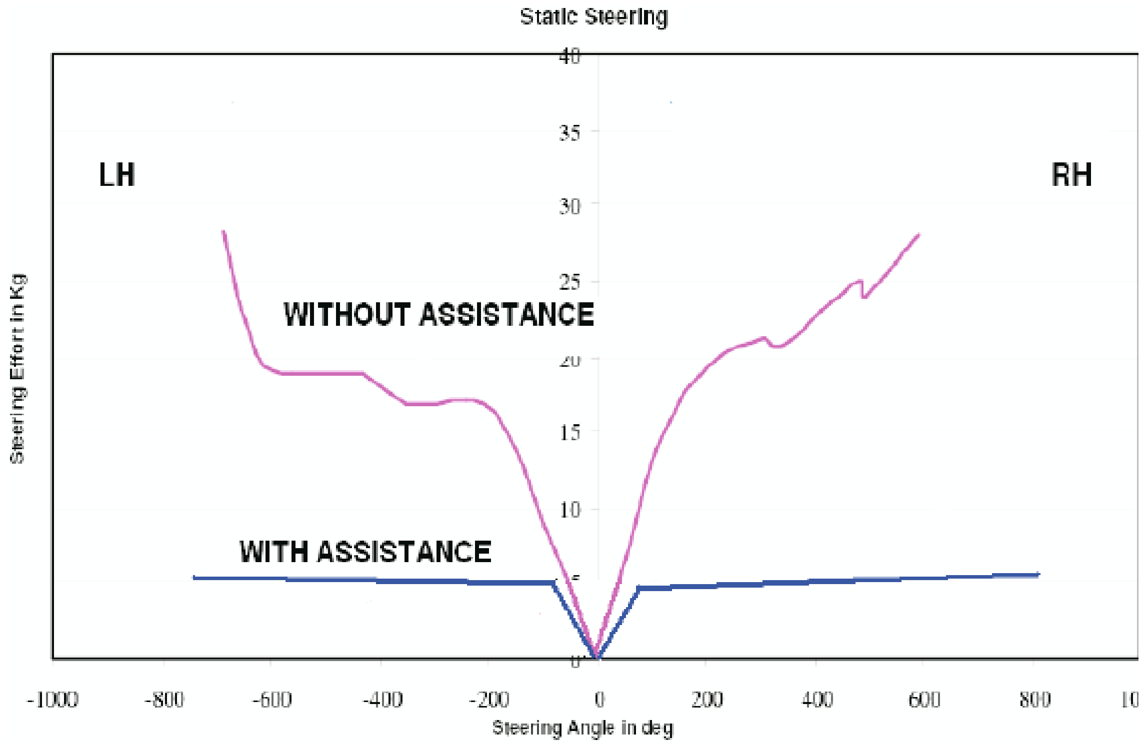


Literature Review Historical background of Power steering

- ***First power steering system was installed by a man with the surname of Fitts in 1876***
- ***Next power steering system was put on a Columbia 5-ton truck in 1903***
- ***First patent for power steering was issued to Robert E. Twyford (USA) on April 3, 1900***
- ***Francis W. Davis, in 1926 invented and demonstrated the first practical power steering system***
- ***The first commercially available passenger car power steering system introduced in the 1951 on the Chrysler Imperial***
- ***The first electric power steering system appeared on the Suzuki Cervo in 1988***
- Control map



Steering Effort



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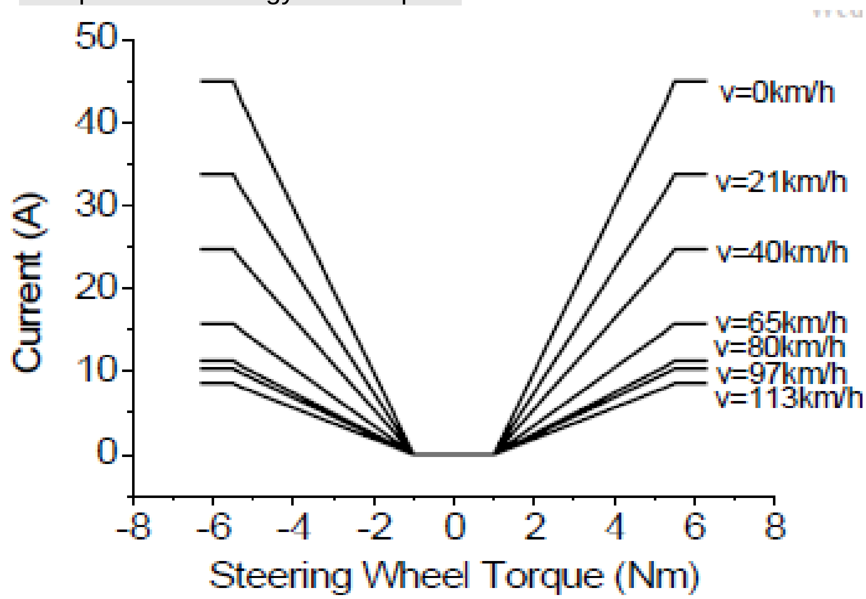
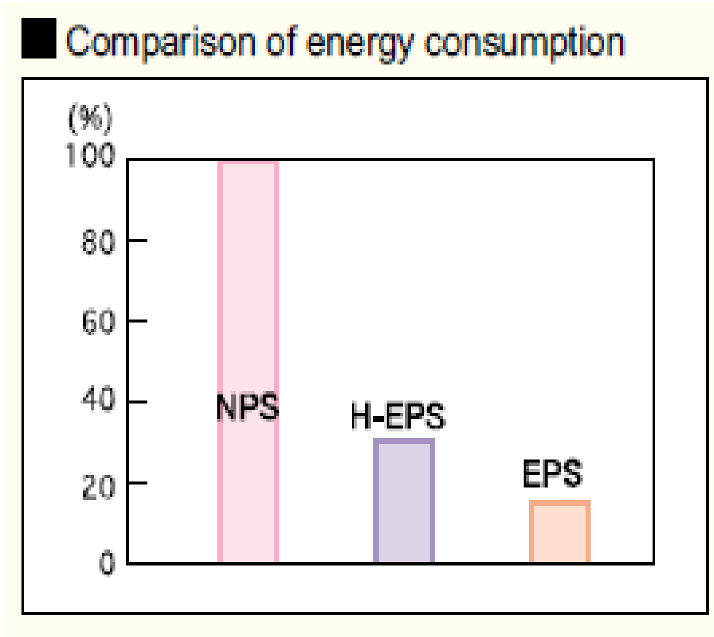
Comparison of energy consumption

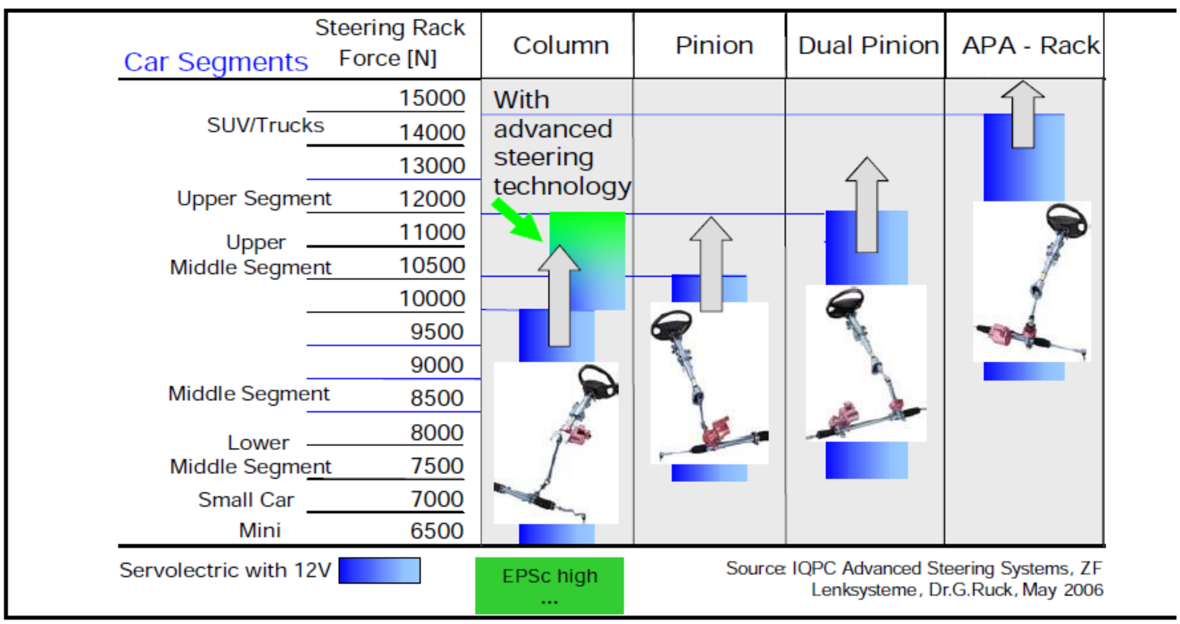


Applications

-



- Applications



No hydraulic components, for example power steering oil pump, hoses, oil tank, filter

- No hydraulic fluid
- Space savings
- Reduction in noise
- Energy savings(fuel saving by 4%)
- No complex hose and wiring system

Chapter 3:

Analysis of Continuous Steering Movement Using aMotor-Based Quantification System

Abstract

Continuous steering movement (CSM) of the upper extremity (UE) is an essential component of steering movement during vehicle driving. This study presents an integrated approach to examine the force exertion and movement pattern during CSM. We utilized a concept similar to the isokinetic dynamometer to measure the torque profiles during 180°/s constant-velocity CSM. During a steering cycle, the extremity movement can be divided into stance and swing phases based upon the hand contact information measured from the hand switch devices. Data from twelve normal young adults (six males and six females) showed that there are three typical profiles of force exertion. The two hands exhibit similar time expenditures but with asymmetric force exertions and contact times in both the clockwise (CW) and counterclockwise (CCW) steering cycles. Both hands contribute more force but with less contact time in their outward CSM directions (*i.e.*, CW for the right hand and CCW for the left hand). These findings help us to further understand CSM and have a number of important implications for future practice in clinical training. Considerably more research is required to determine the roles of the various shoulder muscles during CSM at various speeds.

Keywords: continuous steering movement, torque measurement, hand contact information, steering cycle

Go to:

1. Introduction

Vehicle driving is a common skill of daily living activity in many countries. In Taiwan, almost two-thirds of adults have driving licenses, and average car ownership reached 0.88 per household [1] in 2012. Car ownership rates higher than 500 per 1,000 people are found in more than thirty different countries [2]. Steering wheels control a vehicle's trajectory, and operating steering wheels is a major component of the driving task. To make a hard turn onto a street or to make a U-turn to reverse direction, continuous steering movement (CSM) is essential. Compared to the subtle steering adjustments during straight lane driving, CSM involves movements of almost all upper limb joints in a larger functional range of hand use. To make the wheel rotate, steering torque is exerted on the wheel by the movement of proximal joints of the upper extremities (UEs) with the tangent force applied on the rim of the wheel via hand grasping. During CSM, the UE muscles contract to generate the necessary force or torque, and these muscle activities are a good candidate for UE exercises. Further, CSM features a coordinated and reciprocal use of both hands that is suitable for the bimanual task of rehabilitation training [3,4]. It is interesting and necessary to know the details of the force exertion and movement pattern during CSM to understand the feasibility of using CSM in a therapeutic program for clinical training of disabled patients.

Previous studies have used observation of hand positions [5], video-based motion analysis [6,7], and the electromyography (EMG) technique [8] to understand the movement pattern of the UEs during simulated driving. To see the force exertion during driving, the grip force [9,10] and static torque [11,12] as well as the dynamic [13] steering torque were analyzed. However, previous research was mainly concerned with the issues of driving comfort and ergonomics [11,12] during a small-range steering movement in simulated lane-driving; fewer studies have focused on the force pattern during a larger range of steering [13] or CSM. As the torque measurement is contaminated by the moment inertia of the wheel movement, it is difficult to measure the exact torque profile generated from the driver in dynamic movement or CSM. The measurement is also affected by the design of the torque sensor as the continuous rotation of the steering wheel causes the cords of the torque sensor to become twisted. Moreover, there has been little discussion about movement patterns including the hand contact pattern during the larger-range steering or CSM.

For clinical purposes, the steering exercise might be a good training program for patients suffering from the effects of conditions such as traumatic brain injury or a stroke [14–16]. Before we apply this treatment to pathological patients, the first priority is to understand the characteristics of the steering force exertion and movement pattern. Hence, the aims of the study are twofold. First, we try to develop an integrated measurement system to analyze the torque profile and movement pattern during continuous steering movement. A concept similar to the torque measurement during isokinetic movement [17] was implemented. The steering torque is measured during the motor-driven rotation of a steering wheel at a constant angular velocity to eliminate the inertia problem. Second, the torque profile and movement pattern (temporal and spatial parameters) during CSM are measured and analyzed for 12 normal adults to understand the characteristics of the steering movement pattern. We select the common steering maneuver (cross-handed) to elucidate the force exertion and movement pattern during both clockwise (CW) and counterclockwise (CCW) directions of steering. The differences in hand use between bilateral UEs are also compared and discussed.

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2. Experimental Methods

2.1. System Setup

An integrated system with kinetic and kinematic measurements was developed to analyze the continuous steering movement (as shown in Figure 1). Details of the subparts are described as following.

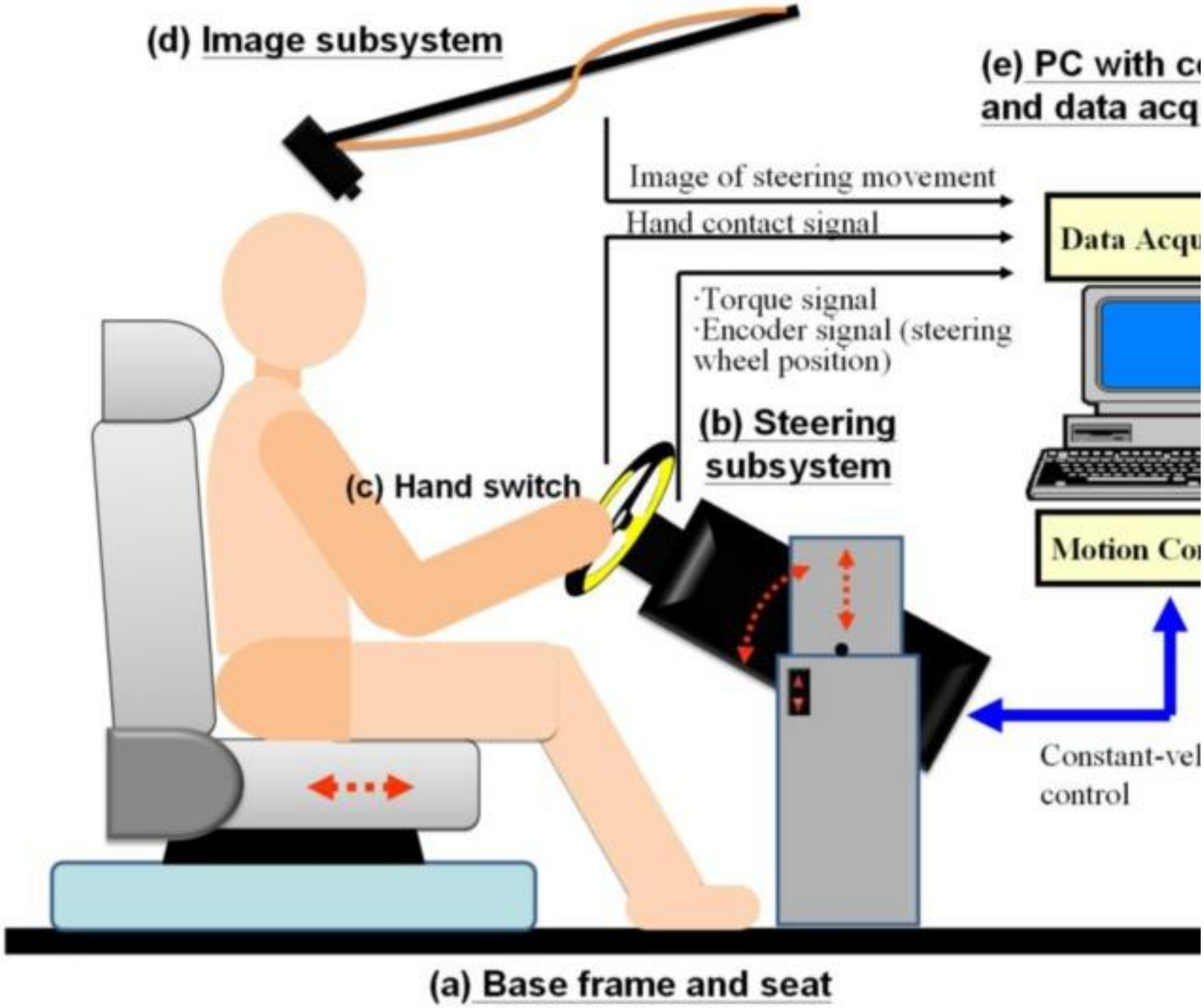


Figure 1.
The integrated measurement system for characterizing steering movement. (**a**) Adjustable base frame and seat for subjects. (**b**) Steering subsystem for torque and position recording. (**c**) Hand switch devices for measuring the status of hand contact on the **...**

2.1.1. Adjustable Base Frame and Seat

As shown in Figure 1(a), the measuring subsystem with a steering wheel was set on a base frame that allows adjustment of the height and tilt angle of the interface. Along with the adjustable seat, the distance, height, and orientation of the steering wheel can be adjusted to fit different subjects and steering postures.

2.1.2. Steering Subsystem

The steering subsystem [Figure 1(b)] was designed to measure the position of the steering wheel and the steering torque during constant-velocity steering movement. Figure 2 shows a diagram of the steering subsystem. Via a rotary torque sensor (DR-2, Lorenz, Inc., Alfdorf, Germany), a 13-inch diameter steering wheel with a grip circumference of about 0.102 m was connected to a 100-to-1 gearbox and a DC servo motor (ASM-T04L250, Delta Electronics, Inc., Taipei, Taiwan). The torque sensor with an integral slip ring assembly can sense the coupled torsion torque between the wheel and the motor, even when the wheel continuously rotates through several full rotations during CSM. The servo motor controlled by the controller in the personal computer (PC) can precisely rotate the steering wheel at constant velocity at a maximum of 35 rpm (210°/s). Besides an internal encoder in the motor, a rotary encoder with a mounted rubber wheel on the shaft [the beige part in Figure 2(b)] was used to record the angular position of the steering wheel. If the rubber wheel and the rotary shaft of the torque sensor have identical circumferences, the encoder and the steering wheel can be made to rotate synchronously by joining them together in a rigid fashion. All components of the subsystem were placed and secured inside a rigid stainless steel box (the black component in Figure 2), which was fixed on the support frame.

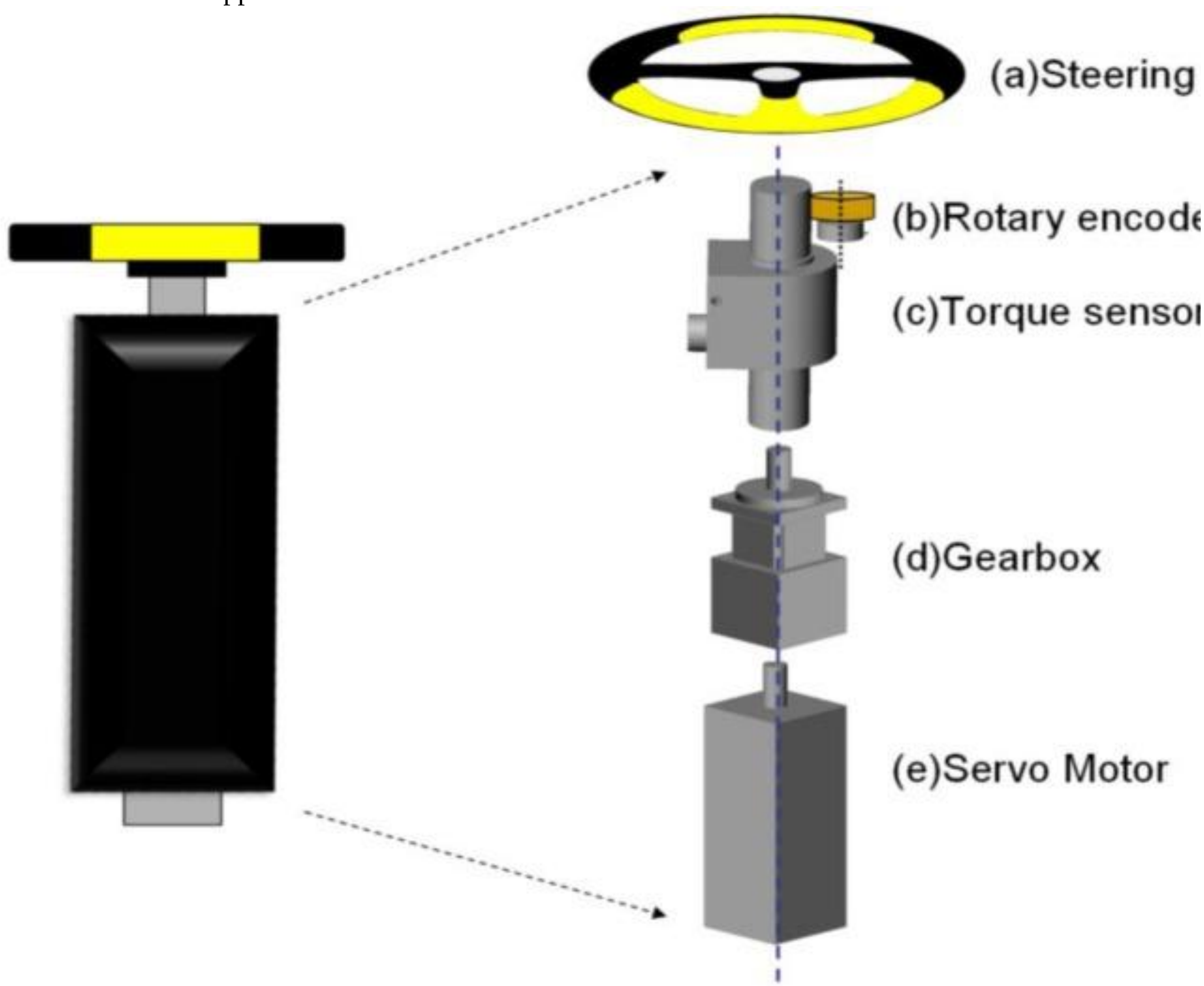


Figure 2.

The steering subsystem. (**a**) Universal steering wheel. (**b**) Rotary encoder (OEW2-36-2MD, Nemicon, Inc.) with a resolution of 14,400 ppr for position recording of the steering wheel. (**c**) Rotary torque sensor with an integral slip ring assembly and a maximal **...**

2.1.3. Hand Switch Devices

To detect the exact time and duration that the subject's hands were in contact with the steering wheel, hand switch devices were used (as shown in Figure 3). Three ultra-thin button switches (5 × 5 × 2.5 mm) encapsulated within two thin plastic membranes were put on each palm in the area of the metacarpal heads and wrapped with a soft wristband [Figure 3(a)]. The status of hand contact on the steering wheel can be encoded as an on-off signal (1 and 0) during steering movement, as shown in Figure 3(b). The hand contact signal also helps to isolate the repetition period of the steering cycle (to be discussed in detail in Section 2.3.1) from a sequence of sensor data.

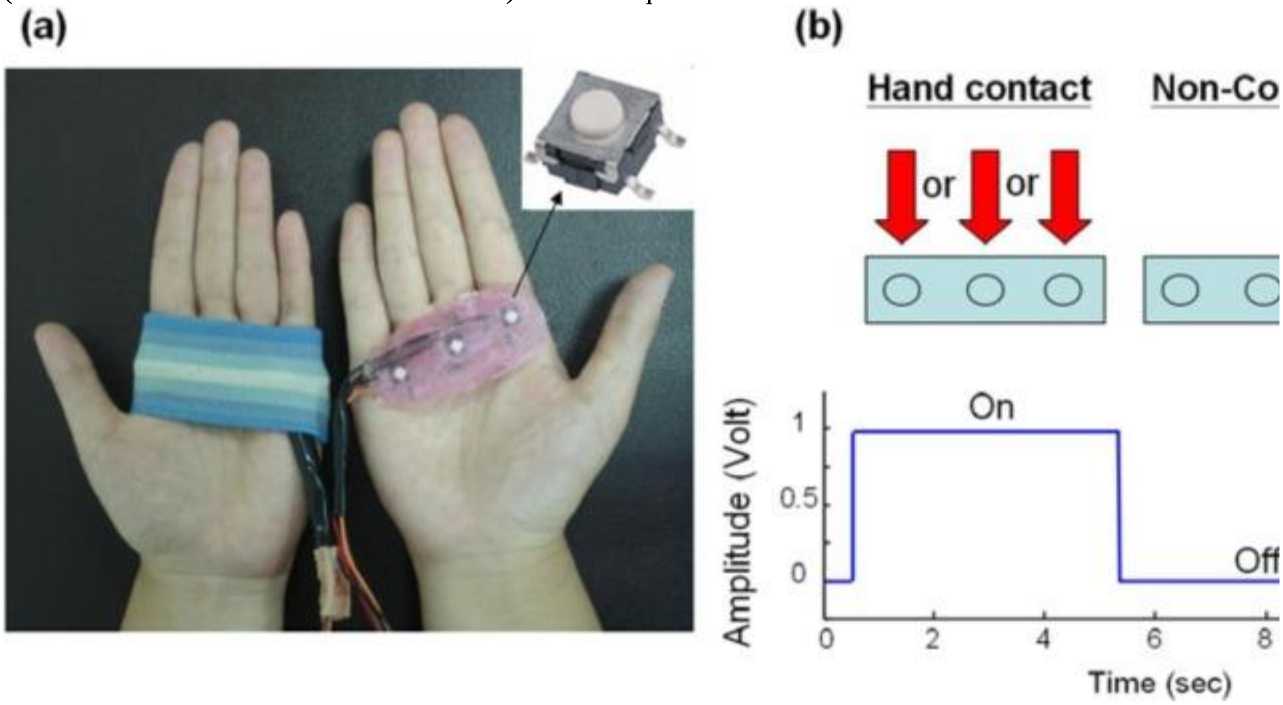


Figure 3.

The hand switch devices. (**a**) Ultra-thin button switches were used to sense the contact status of both hands (where the wristband has been removed from the right hand in order to display the button switches). (**b**) When any of the button switches senses **...**

2.1.4. Image Subsystem

A monochrome camera (scA640-70fm, Basler, Inc., Frankfurt, Germany) was also used to record the steering movement [Figure 1(d)]. The camera captured images of the steering wheel area with a sampling rate of 10 frame/s and a resolution of 640 × 480 pixels and sent the resulting images to the PC through an IEEE 1394b card.

2.1.5. PC-Based Controller and Data Acquisition Subsystem

As shown in Figure 1(e), a personal computer was used to administer the data acquisition and servo motor control. The measured torque, position, and hand switch signals were acquired by the PC through a 12-bit A/D converter (PCI-6259, National Instruments, Inc., Austin, TA, USA) at a sampling rate of 1 kHz for storage and display of the data. A motion control board (PCI-7350, NI Inc.) was installed in the PC as a proportional integral-derivative (PID) controller to control the movement of the servo motor and to rotate the steering wheel at a constant velocity via a servo drive (ASD-A0421LA, Delta Electronics, Inc., Taipei, Taiwan). To ensure that the continuing rotation of the steering wheel comes from the exertion of the subject, we set a criterion for controlling the wheel movement. Figure 4 depicts the diagram for motor control of the steering wheel at a constant velocity of rotation. In a control loop operating at 16 kHz (checked every 62.5 µs), the servo motor rotates at a selected constant velocity only when the applied torque (T_s) exceeds the predetermined threshold of 0.5 N·m. The torque threshold was tested and determined before the experiment, and it was found to be easy for all subjects to rotate the steering wheel continuously.

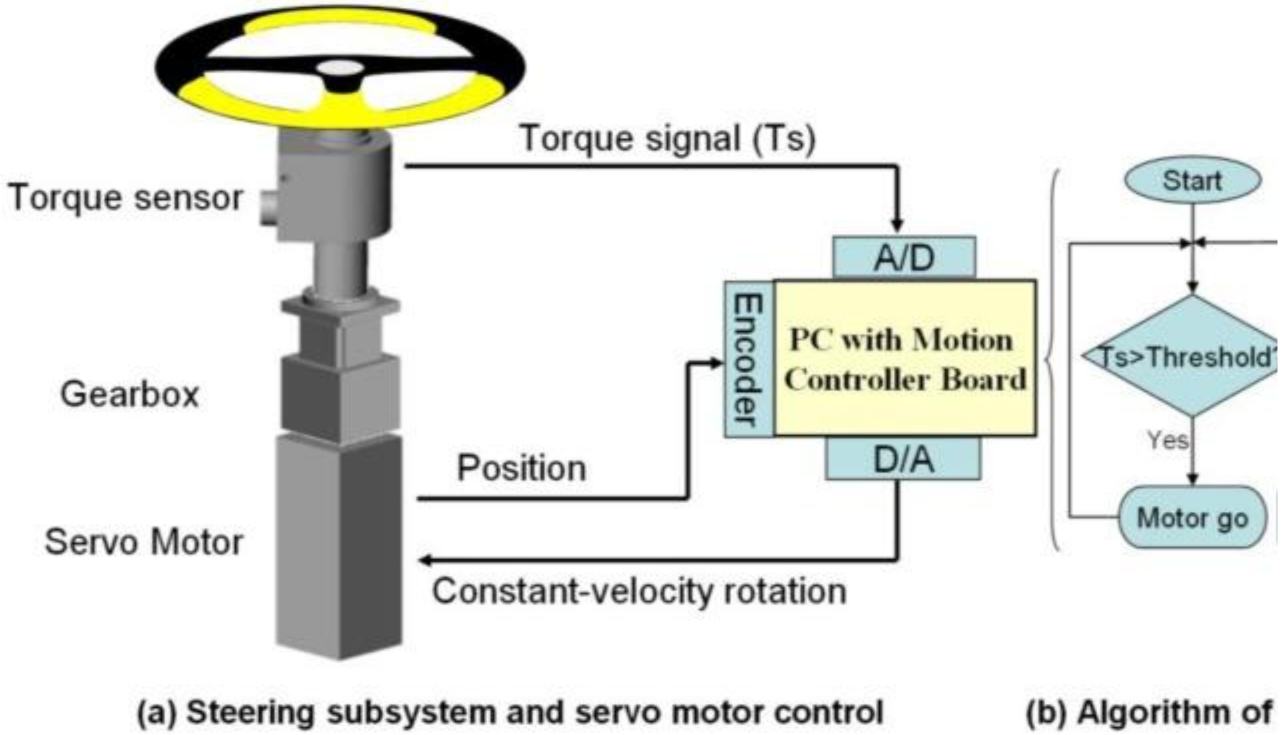


Figure 4.

Control flow diagram for the continuous steering movement. (**a**) Steering subsystem provides the position and torque of the steering wheel to the controller and receives the command to rotate it at a constant velocity if the criterion in (**b**) is met. The **...**

2.1.6. Software Interface

A customized LabVIEW-based program (Version 8.5, National Instruments, Inc., Austin, TA, USA) with an integrated user interface provides for the setting of parameters, display of data, and saving of position, torque, and image signals during the experiment. Furthermore, the subject can consult the PC screen in order to visualize the amplitude of the applied torque to help them keep the steering wheel rotating continuously.

2.2. Experimental Design

Twelve right-handed young subjects (six male, six female, with ages ranging from 20 to 25 y/o) agreed to volunteer for the following experiment. All of the subjects had no previous neurological disorders and had had no orthopedic problems in the six months prior to the test. Before the testing, each subject was instructed in the testing procedure and was allowed five minutes of steering practice to determine the proper body position for continuously steering by adjusting the base frame or seat. The anthropometric relations between the subject and our system can be understood from the following measured data. The shoulder width (SJ2SJ) was larger than the diameter of the steering wheel in almost all of the subjects (except s4 and s5, who are rather short). A general rule for selecting the seat position is to find the position such that when the subject reaches his or her hand toward the wheel, the wrist is about to touch the upper edge of the wheel; the subjects then handle the steering wheel in a posture of slight elbow flexion. This position can also be determined by the smaller distance from the shoulder joint to the steering center (SJ2SC, ranging from 46 to 56 cm), compared to the UE length (SJ2FT, ranging from 65 to 78 cm). The fact that the center of the steering wheel is lower than the shoulder joint was noted in all subjects, as the distances of SC2FL (steering center to floor) are smaller than those of SJ2FL (shoulder joint to floor). The selected tilt angle (TA) of the steering wheel ranged from 69° to 78°. Details of the participants' characteristics, including height, weight, anthropometric measurements, and the self-selected tilt angle of the steering wheel, are summarized in Table 1.

Table 1.

Participant profiles.

Subject No.	Sex	Height (cm)	Weight (kg)	SJ2SJ (cm)	SJ2SC (cm)	SJ2FT (cm)	SJ2FL
s1	M	169	50	36.5	53.5	73	78
s2	M	180	70	39	56	78	81
s3	F	170	80	37	50	72	78
s4	F	156	50	32.5	49	66.5	75
s5	F	157.5	53.5	33	46	65	7[illegible]
s6	F	157	50	33.5	49.5	65.5	76
s7	F	168	58	34	52	74	81
s8	M	170	60	38	54	73.5	76
s9	M	168	59	38	51	73.5	75
s10	M	177	70	40	55	77	79
s11	F	171	57	35.5	51	72.5	8[illegible]

Table 1.
Participant profiles.

As the steering wheel driven by the servo motor does not rotate when the subject stops turning it (Figure 4), all the subjects were asked to maintain continuous rotation of the steering wheel without interruption and were monitored to confirm this behavior. All subjects continuously rotated the steering wheel with the cross-handed maneuver in both clockwise and counterclockwise directions for at least one minute at the testing steering velocity of 30 rpm (180°/s). The velocity of 180°/s was selected, as it reaches the velocity of the authors' real driving experience during fast turning. To eliminate the effect of trunk involvement, the subjects were instructed to not leave the seat back and were monitored by the instructor during the CSM trials.

2.3. Data Analysis

2.3.1. Steering Cycle

For each extremity, a steering cycle can be defined as the time period between two adjacent initial hand contacts, and it can be divided into contact and non-contact phases according to the hand switch signals. As shown in Figure 5, we provide an illustration of the steering cycle based on the information we have observed from the video captured by the image subsystem [Figure 5(e)]. During a steering cycle, the events and patterns of hand movements are similar to a gait cycle which includes a stance phase and a swing phase according to whether the hand/foot contacts the ground/wheel [18]. In a cycle of the CCW steering movement, the right hand initially contacts the wheel and holds and pulls it to move it to the left, while the left hand continues working on the wheel (the first double stance in Figure 5). In this case, as the left hand would, within a short duration, become ill-equipped to apply force, the hand would then unclench and swing across the right hand to a new position (left-swing phase), while the right hand would continue working on the wheel (beginning of the 2nd double stance). When the right hand also progresses to the point that it is in a poor position to apply force, the right-swing phase begins, and it ends at the next right initial contact.

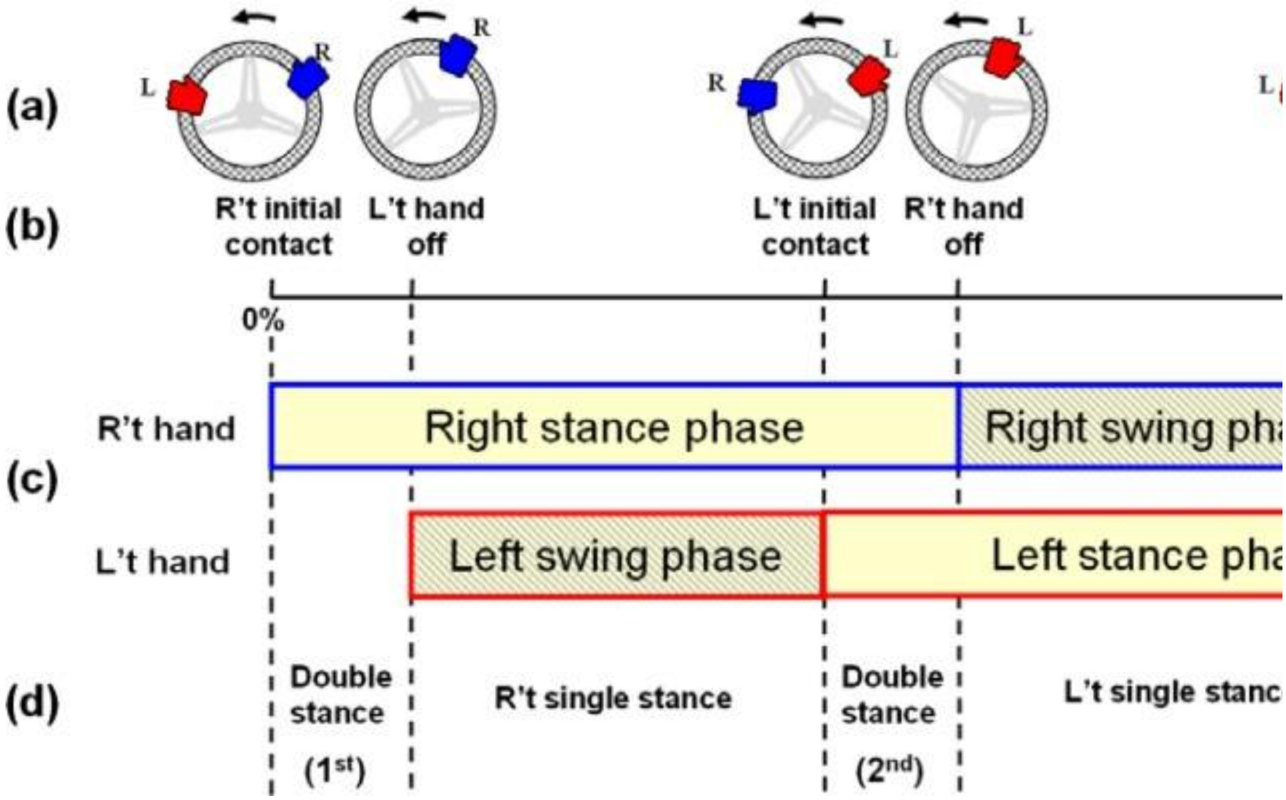


Figure 5.

Steering cycle during a counterclockwise (CCW) steering movement. (**a**) Hand positions during the steering cycle. (**b**) Events in which the hands either made contact with the steering wheel or released the steering wheel. (**c**) Stance and swing phases for both **...**

2.3.2. Analyzed Parameters

For each steering trial, at least eight successive steering cycles were selected for further analysis. By using the hand switch signals, all the data (torque, hand switch signals, and steering position) in each steering cycle was reduced to a normalized frame of 512 data points (100% steering cycle) for convenience. Further, the exerted torque signal and the displacement signal of the encoder were rectified to present the absolute values in the following analysis. We analyzed the continuous steering movement from the viewpoints of both the kinetic and kinematic aspects for each steering direction. In the kinetic aspect, we derived the averaged amplitude of the torque during the single stance phase for each hand to understand the contribution of the right and left hands to the torque profile. The averaged amplitude of the torque, T_{amp}, was defined as:

$$\mathrm{T}_{\mathrm{amp}} = \frac{\sum_{n=1}^{k} T[n]}{k} \quad (1)$$

where $T[n]$ represents the torque amplitude of the nth data point and k denotes the duration of the torque (in units of data sample points) during the single stance phase.

In the kinematic aspect, the temporal parameters include the cycle time, stance time, swing time, and stance ratio. Cycle time, stance time, and swing time are defined as the durations of a steering cycle, stance phase, and swing phase respectively. The stance ratio is the ratio of the stance time to the cycle time. For the spatial parameters, the averaged rotary displacements for each hand were analyzed in units of complete rotations. Furthermore, the video from the image system was also included and helped to observe and verify the sequence of movements of the upper limbs. In the statistical analysis, a paired*t*-test was used to test the difference between the parameters derived for the two hands or the two steering directions. P values below 0.05 were considered statistically significant.

2.4. Issues of System Performance and Measurement

To ensure the reliable and valid measurement of kinetic and kinematic parameters, several approaches were taken. First, the continuous rotation of the steering wheel and hand switch signals were monitored online during each trial. Any data involving interruptions in the rotation or bad hand switch contacts were rejected, and the subject was asked to repeat the trial. Second, raw torque signal for all trials were screened by the authors to confirm the signal stability before further analysis. Torque parameters for a trial were averaged over at least eight steering cycles to reduce the possibility of random interference affecting the signal. Third, the prepared procedures including the position adjustment and the pretrial practice also help to enhance the validity of the measurement.

Furthermore, the captured video from the digital video recorder was screened to confirm there is no any unwanted trunk involvement during CSM trials.

To demonstrate the system performance and measurement results, two typical examples of processed data based upon the steering cycles of the right hand were shown in Figure 6. During the CW and CCW steering trials, the displacements of the steering wheel were 282.23° and 258.00° with the derived averaged velocities of 180.56°/s and 180.42°/s. The linear displacement and constant velocity ensured the performance of the motor control. The steering torque during the cycle and the events of the first double stance (both hands on), right single stance, second double stance, and left single stance phases can be easily observed. Overall, the accurate measurement of signals (especially torque) during constant-velocity steering was confirmed.

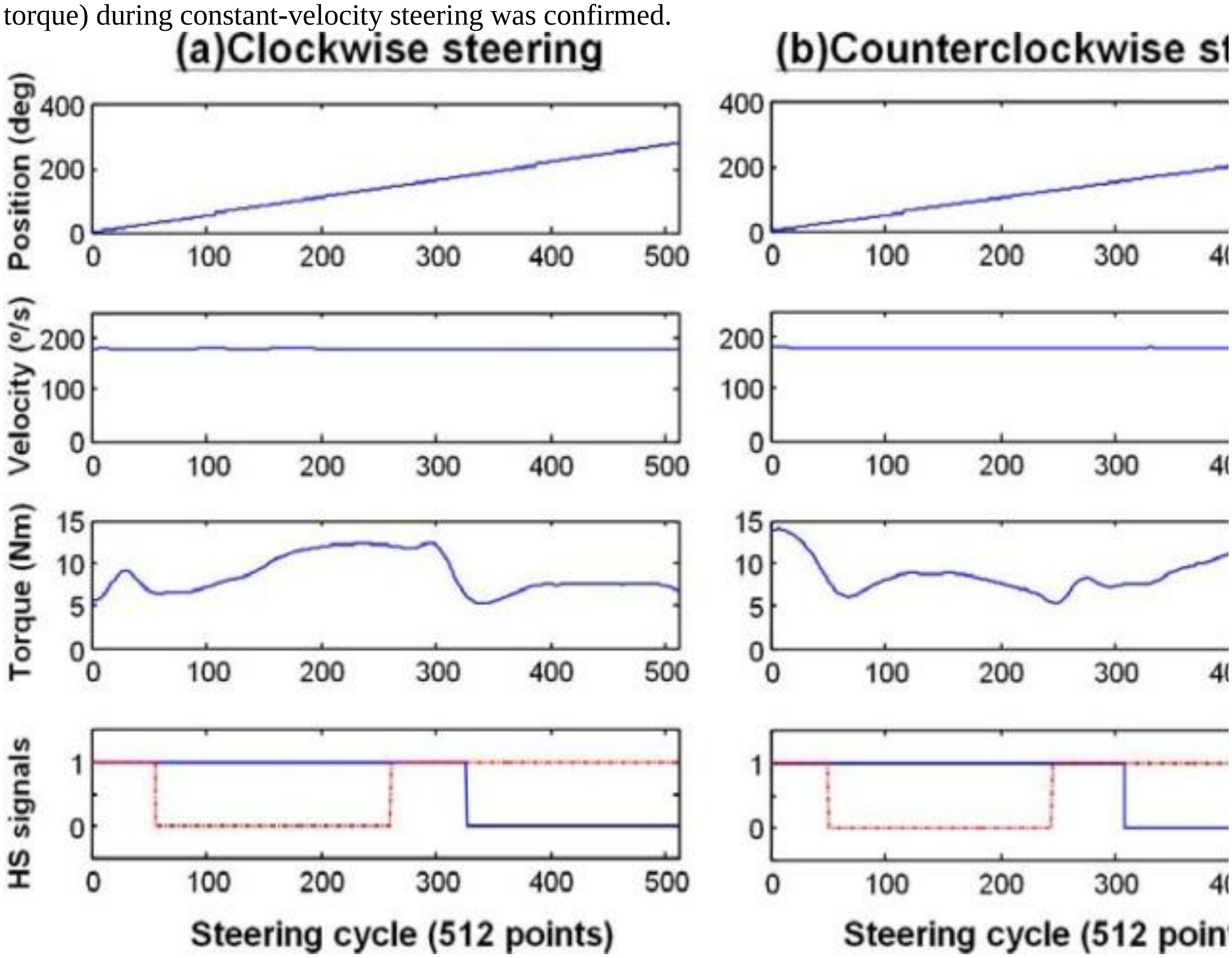


Figure 6.

Processed data of position, velocity, torque, and hand switch (HS) signals from one subject (S7). The velocity and torque signals are processed with a low-pass filtering of 100 Hz. The duration and timing of all these data signals were extracted from **...**

Go to:

3. Results

3.1. Kinetic Aspect: Torque Profile

As the steering wheel rotates at constant velocity, the steering torque can be measured without the effects of acceleration and deceleration of the wheel. As shown in Figure 7, we present three types of torque profiles to elucidate the features of force exertion in continuous steering movement. Compared to the torque profile of the CCW steering shown in Figure 6(b), we process the CCW data with respect to the left hand switch signal [Figure 7(d–f)]. Interestingly, the plots show that the torque signal can be divided into two major force exertions which are separated by a major dip after the second double stance (marked by the red vertical dash line) for both CW and CCW steering. In the torque profile before the major dip, a small ripple may appear in the first double stance [Figure 7(a,c,d,f)] or the second double stance [Figure 7(b,c,e,f)]. The small ripples are believed to be made by the hand contact of the swing hand. If the transition of the hand exchange is made more smoothly, the ripple effect might be diminished and may even disappear [second double stance of Figure 7(a,d) and the first double stance ofFigure 7(b,e)].

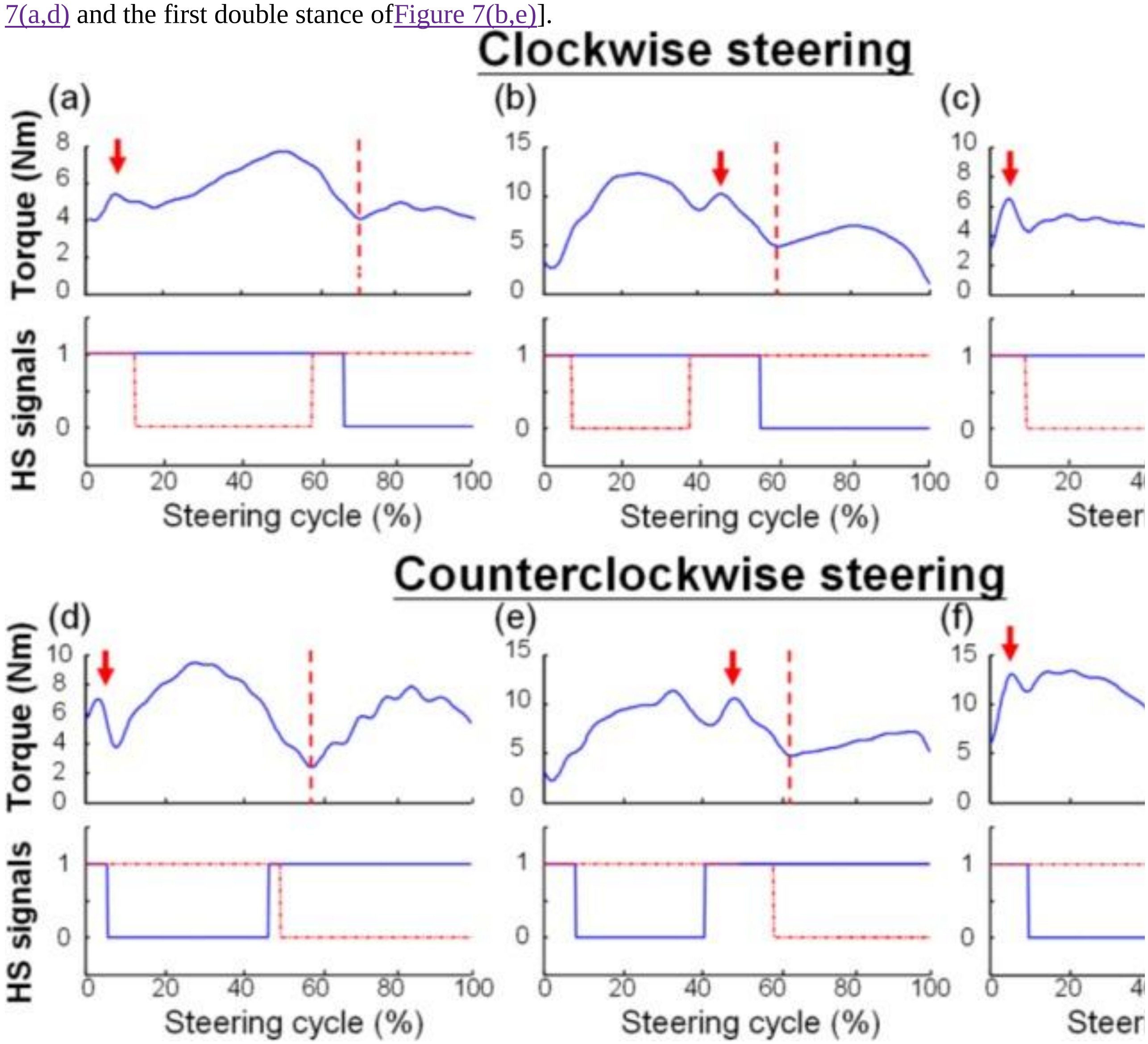


Figure 7.

Three types of torque profiles (CW *vs.* CCW). Type 1: A ripple is only found in the first double stance of (**a**) and (**d**). Type 2: A ripple is only found in the second double stance of (**b**) and (**e**). Type 3: Ripples are found both in the first and second double **...**

To understand the contribution of hands to the torque profile, we compared the averaged amplitudes of the right and left hands in their single stance phase (Table 2). For CW steering, the torque amplitude is significantly larger for the right hand (8.23 ± 2.65 N·m), compared to the left hand (5.94 ± 1.51 N·m) with statistical significance ($P < 0.05$). In contrast, the amplitude of the torque in the left hand (8.04 ± 2.42 N·m) is significantly larger than that of the right hand (5.43 ± 1.42 N·m) for CCW steering ($P < 0.05$).

Table 2.

Averaged amplitudes of torque during single stance phase (Unit: N·m).

(n = 12)		Mean (SD)	*P* Value
CW	Right	8.23 (2.65)	0.001 *
	Left	5.94 (1.51)	
CCW	Right	5.43 (1.42)	<0.001 *
	Left	8.04 (2.42)	

CW: clockwise steering; CCW: counterclockwise steering.

*The symbols denote a significant difference between the torque amplitudes fc as evidenced by the fact that $P < 0.05$.

Table 2.

Averaged amplitudes of torque during single stance phase (Unit: N·m).

3.2. Kinematic Aspect

3.2.1. Temporal Parameters

As summarized in Table 3, the averaged cycle times of the right and left hands are equivalent for either CW or CCW steering (about 1.60 and 1.53 s, respectively). However, a significantly longer stance time and a shorter swing time (*i.e.*, a higher stance ratio) were noted for the left hand for CW steering and in the right hand for CCW steering (all of which had $P < 0.05$).

Table 3.

Temporal parameters: cycle time, stance time, swing time, and stance ratio durin

(n = 12)		Cycle Time (s)		Stance Time (s)		Swing Time (s)		St
		R′t	L′t	R′t	L′t	R′t	L′t	R′
CW	Mean (SD)	1.60 (0.25)	1.60 (0.25)	0.87 (0.13)	1.00 (0.17)	0.73 (0.18)	0.61 (0.12)	0.55 (
	P value	0.131		0.027*		0.031*		
CCW	Mean (SD)	1.53 (0.25)	1.53 (0.24)	0.95 (0.19)	0.84 (0.13)	0.58 (0.09)	0.69 (0.14)	0.62 (
	P value	0.795		0.006*		0.007*		

CW: clockwise steering; CCW: counterclockwise steering.

*The symbols denote a significant difference in parameters between the left ar evidenced by the fact that $P < 0.05$.

Table 3.

Temporal parameters: cycle time, stance time, swing time, and stance ratio during CW and CCW steering.

3.2.2. Spatial Parameters

In the study, the subject completed a steering cycle with less than one rotation (either right or left), varying from 0.53 to 0.99 rotations with an average of 0.8 ± 0.13 rotations in the CW direction and 0.76 ± 0.12 rotations in the CCW direction (where one complete rotation = 360°). There is no significant difference in cycle displacement between CW and CCW steering ($P = 0.201$).

Go to:

4. Discussion

In this preliminary study, we developed a measurement system to analyze the torque profile and movement pattern of continuous steering movement. We utilized an idea similar to the basis of isokinetic dynamometry [17] to elucidate the force exertion pattern during a constant-velocity steering movement. Measuring the torque during a constant velocity motion of the steering wheel controlled by the motor has successfully eliminated the inertial problem of the wheel caused by the acceleration and deceleration of the rotating motor (as shown in Figures 6 and and7).7). The movement pattern of CSM, especially the hand contact on the steering wheel, was studied within a steering cycle (as shown in Figure 5). By using the hand switch devices, the temporal parameters including steering cycle time, stance time, swing time, and stance ratio could be analyzed. Our system has provided a unique approach to study the steering movement and has improved the understanding of UE movement during CSM.

The main results of the CSM analysis could be summarized in terms of the kinematic and kinetic aspects. In terms of the kinematics, CSM features the reciprocal movement of two upper extremities in an asymmetric movement pattern. The movement of each extremity can be partitioned into a stance phase, where the hand is in contact with the wheel, and a swing phase, where the hand is lifted and moved sideways to prepare another stance. In our study, each extremity for a given subject completes a cycle in a similar period of time but with an asymmetric ratio of hand contact (as indicated by the stance ratio listed in Table 3). A shorter duration of right hand contact in CW steering and left hand contact in CCW steering were found as the reachable areas of the steering wheel are different for the two hands in the CW and CCW directions. As a reciprocal movement pattern of the UEs, the pattern of time periods and events during a steering cycle are similar to those in the gait cycle of the lower extremities (LEs) [19], although CSM is predominately open-chain kinematic movements of the UEs [20], compared to the combination of open-chain and closed-chain movements of the LEs during a gait cycle. We hope the proposed steering cycle in the study helps researchers to better understand and study the continuous steering movement.

In terms of the kinetics, we found that all the subjects exhibited a similar torque profile pattern with two major exertions combined with one or two ripples in the transition of the hand change during a CSM cycle (Figure 7). These ripples, mainly occurring during the double stance phases, might indicate the proficiency of steering movement, which could be evaluated by the amplitude of the ripples. For a coordinated performance of the bimanual task, the exchange of hand contact might be smooth and the ripples might be small or disappear. Moreover, the contribution of torque exertion is asymmetric with right domination in the CW direction and left domination in the CCW direction (both are in their abduction directions). Interestingly, the hand that exerts more force on the rotation of the wheel has a shorter contact duration, while the other hand has a longer contact duration but a smaller contribution to the rotating torque (as indicated by the data in Tables 2 and and3).3). Independent of dominant hand use, the asymmetric contribution of the UEs indicates the differences of muscle use and functional range between the two hands. Although previous studies have found that the shoulder adductor is stronger than the abductor during isokinetic contractions [21,22], the combination of the effects of the constrained areas that are reachable by the two hands and the effective muscle length on maximal exertion largely contributed to the asymmetric pattern of the UEs. Therefore, ergonomic factors such as wheel size, operating distance, and operating height are suggested for consideration in CSM analysis. The contribution of different muscles during CSM could be further analyzed using our system with additional EMG measurements. Furthermore, the velocity of wheel rotation might also affect the movement pattern of CSM as the contact duration and hand use might change to adapt to the requirement of continuous motion. In this study, we selected the angular velocity 180°/s which is considered medium to fast for isokinetic exercise [23,24]. These data must be interpreted with caution as the kinetic and kinematic parameters might change when using a slower or faster velocity of wheel rotation, and we may investigate this effect in the future.

In the methodological aspect, several approaches including the preparation work before the test, online monitoring during the test, and verification as well as data processing after the test have been used to enhance the reliability and validity of measurements. These approaches were valid methods to reduce the measurement errors [25,26] and could be recommended for the future quantitative study on driving movement. In pretrial practice, we also noted that some subjects tried to turn the steering wheel with trunk rotation involvement if the subjects sat too far to the wheel. As a previous study showed that trunk involvement might reduce the elbow and shoulder use during the reaching movement [27], we decided to minimize the effect by selecting the proper position of the subject with respect to the steering wheel as well as asking the subject not to leave the seat back during CSM and monitoring them to ensure that they did so. Nevertheless, trunk involvement is allowed and common in real driving situations. The associated effects of trunk involvement on UE use during CSM might need to be studied further in the future.

Obviously, vehicle steering is a complex process that involves the brain, muscles, and limbs in response to demanding driving situations. Among the movements of vehicle steering, CSM might be the more challenging parts as CSM involves a large movement range and intra-limb and inter-limb coordination [28]. We believe CSM could be a good exercise program for pathological patients if the involved muscles under various conditions (considering ergonomic factors and rotating velocity) could be fully understood. Compared to previous systems developed for the purpose of rehabilitation [15,29], our system provides not just the outcome of a steering movement (the position of the steering wheel) but also information on the force exertion and hand contact of the CSM, which can be used for further analysis. In future, we might utilize the information as a feedback signal for movement training of pathological patients suffering from conditions such as traumatic brain injury or stroke. The system might also be used to evaluate the motor ability of pathological subjects who want to return to normal driving as it offers tremendous advantages over traditional driving assessment tools [30–32] in a more objective and reliable manner.

Go to:

5. Conclusions

In this study, we have developed an integrated measurement system to study the continuous steering movement. To our knowledge, no previous study has focused on the movement pattern and force exertion during CSM. We found that CSM is a repeatedly and reciprocally bimanual task with asymmetric contributions from the two hands. This information can be used to develop targeted interventions aimed at improving strength and coordination of the UEs after injuries. A future study investigating the various muscles used during CSM would be very helpful and interesting.

Chapter 4

Vehicle stability control strategy for steer by wire system

Abstract

It has been confirmed through sudden-brake test on μ-split roads, etc. that great vehicle stability is achieved by automatic front-wheel steering control. Steer by wire prevents unnecessary forces from reaching the driver because it eliminates the direct mechanical linkage of a conventional steering column. By using D∗control, this system can offer high steering response and reduced driving effort, among other benefits. The effectiveness of the proposed control was investigated on a driving simulator and by actual vehicle testing, and we attempted to achieve control parameter optimization by investigating the relationship between control parameters and vehicle dynamics by computer simulation.

Figures and tables from this article:

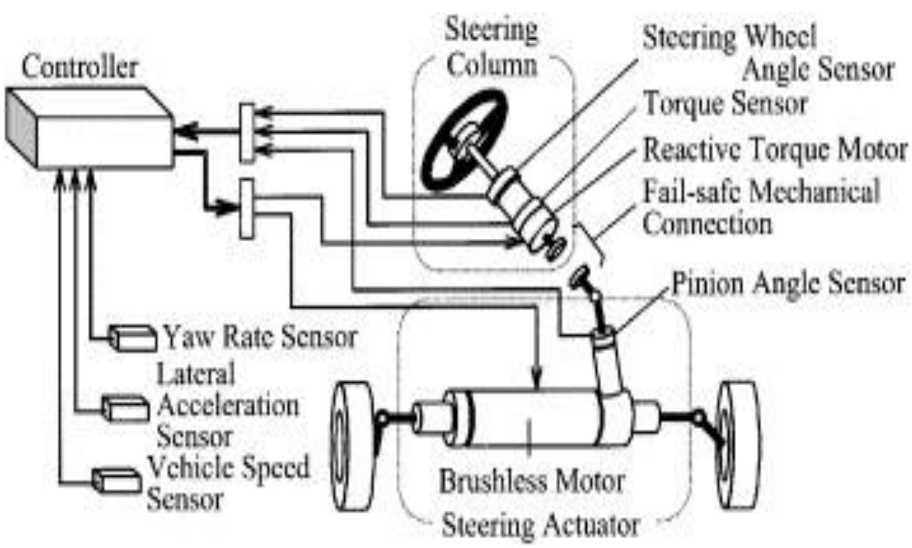


Fig. 1. System construction.

Figure options

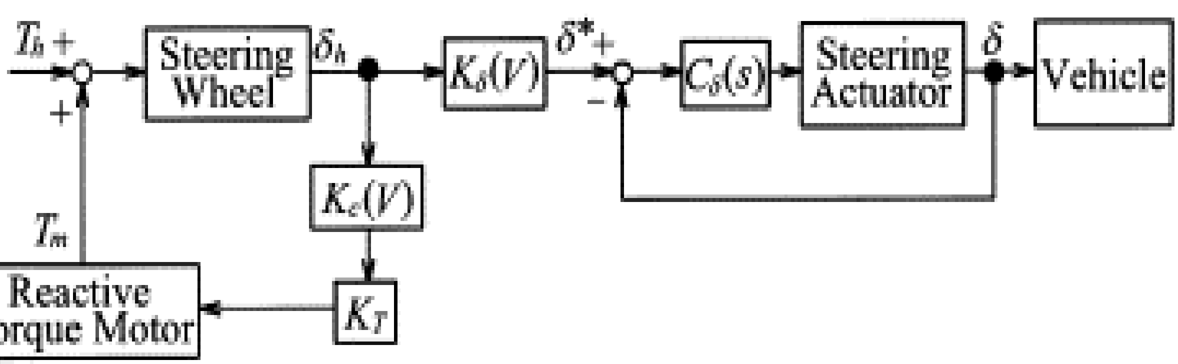


Fig. 2. Block diagram of front wheel angle control.

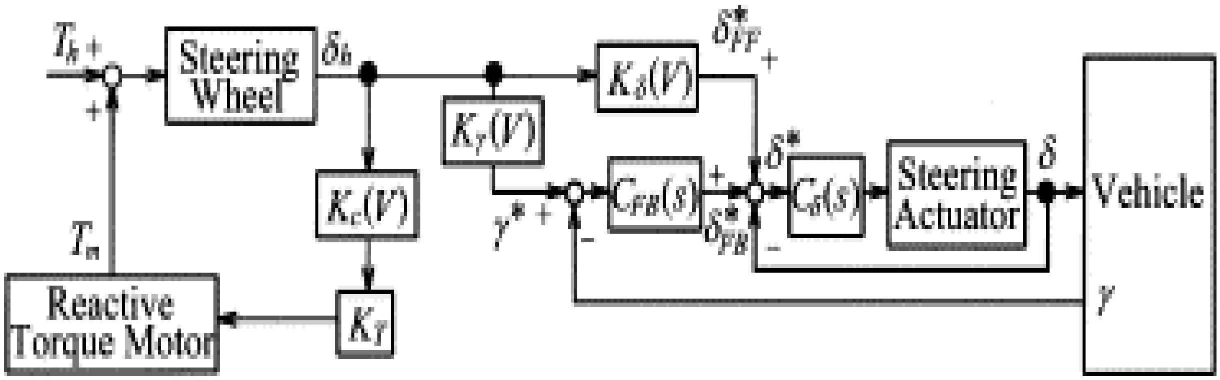


Fig. 3. Block diagram of yaw rate control.

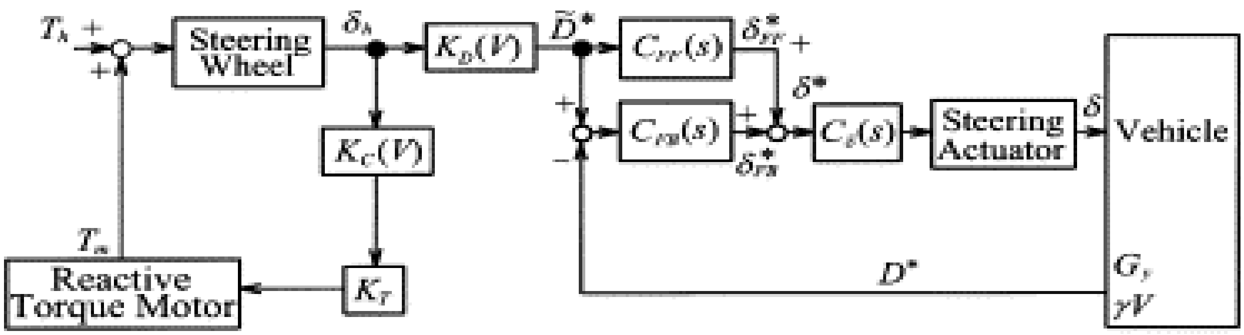


Fig. 4. Block diagram of D∗ control.

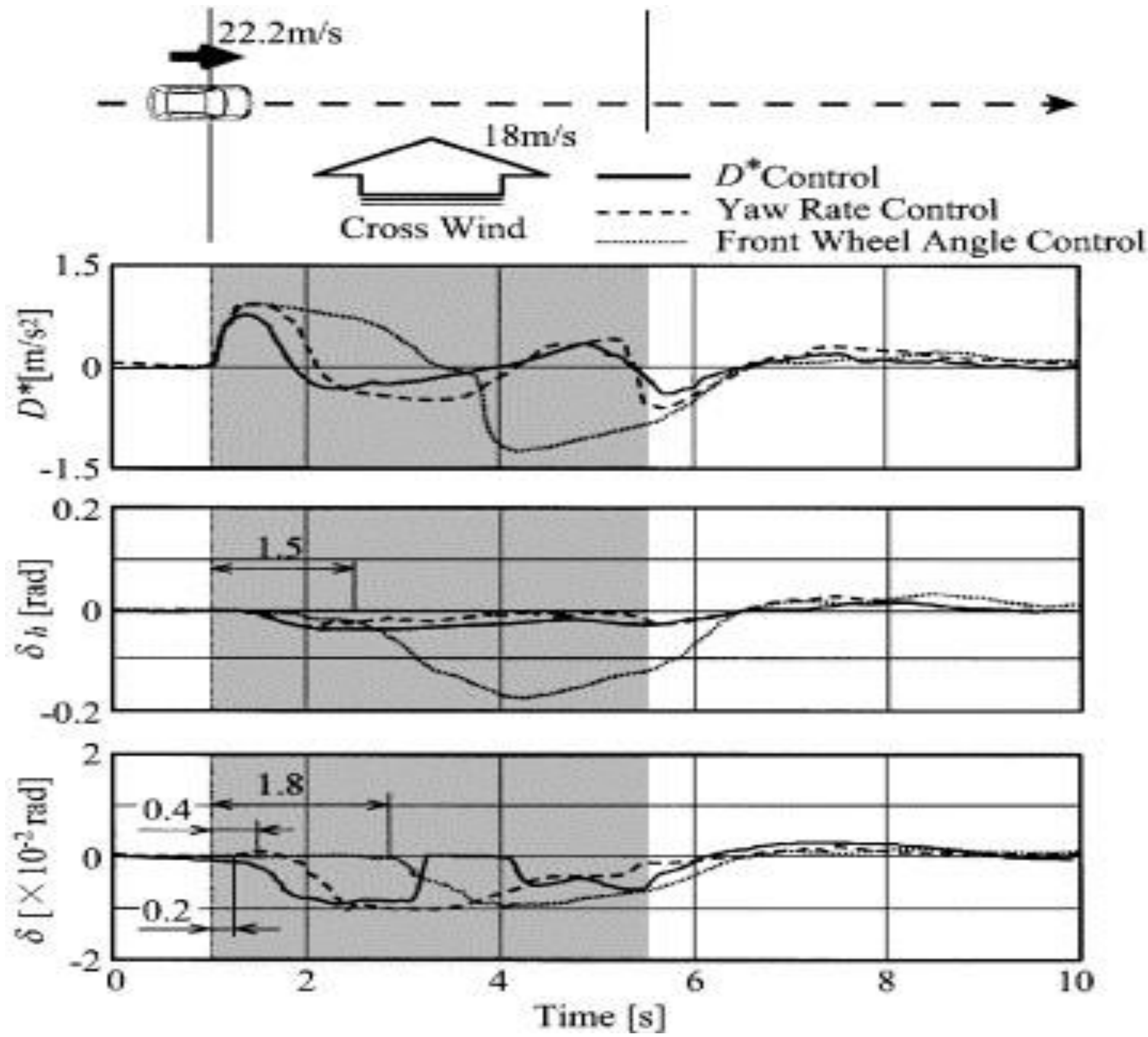


Fig. 5. Vehicle behavior against cross wind.

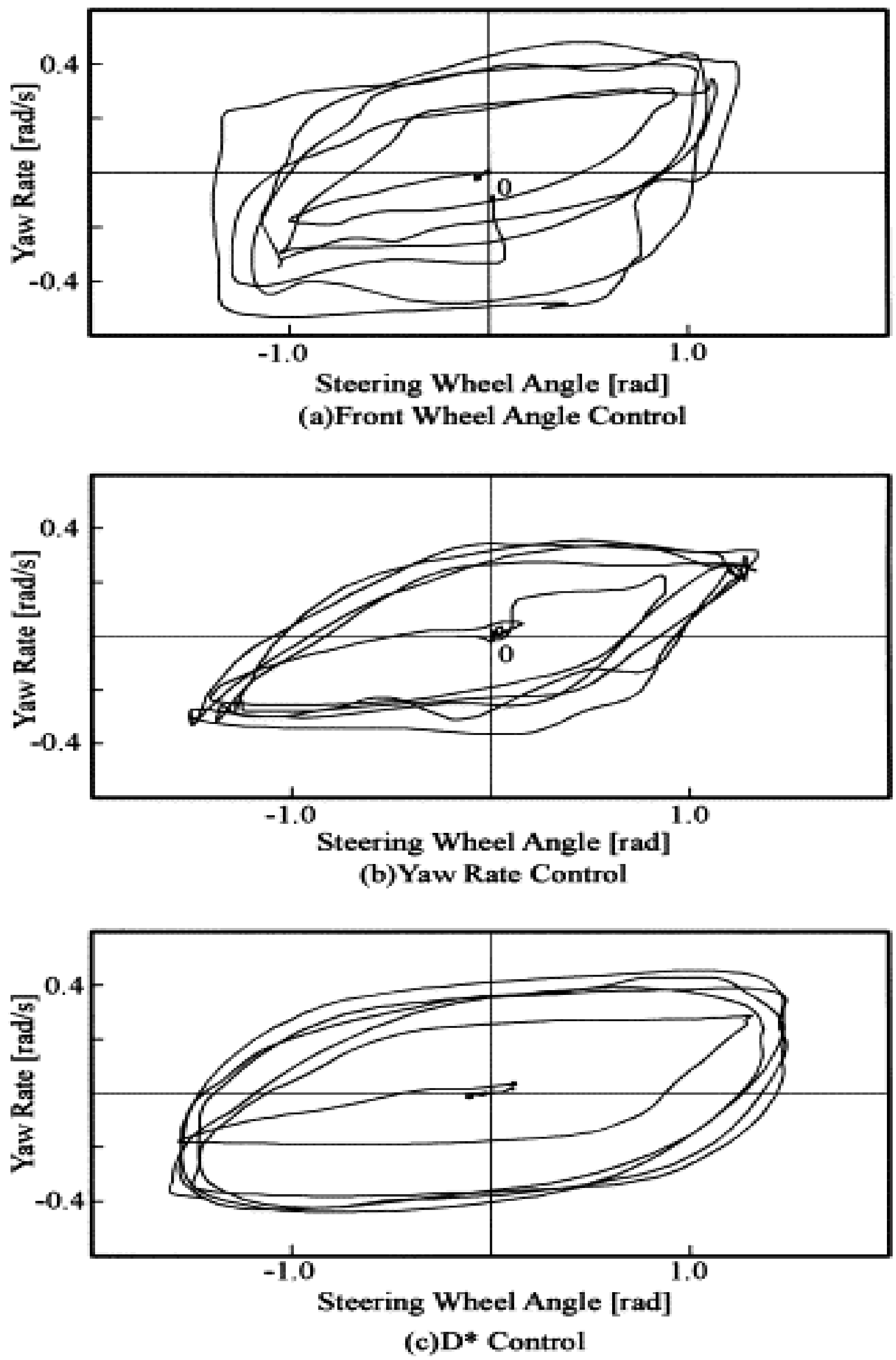


Fig. 6. Results of Slalom test on packed snow.

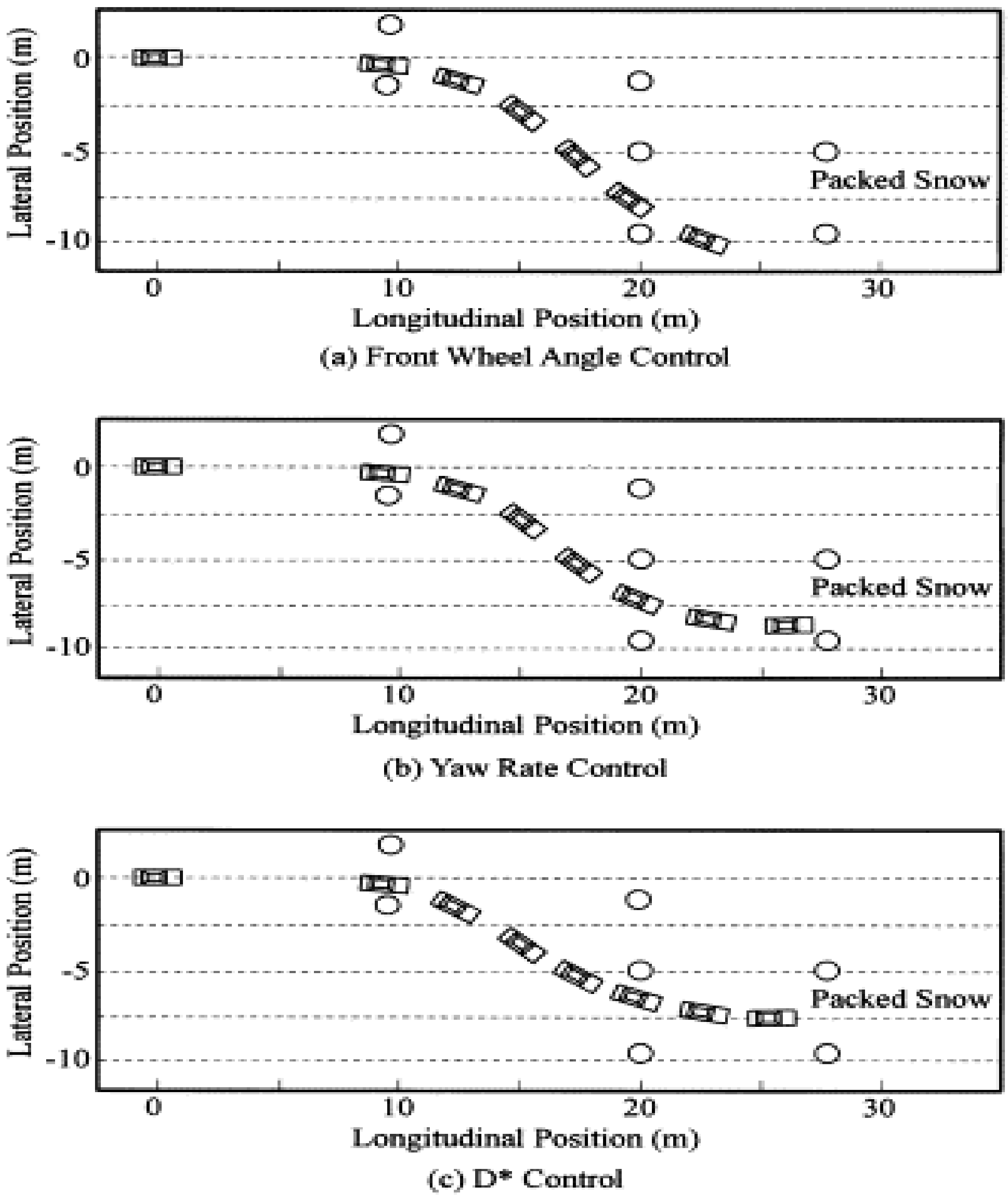


Fig. 7. Results of lane-change test.

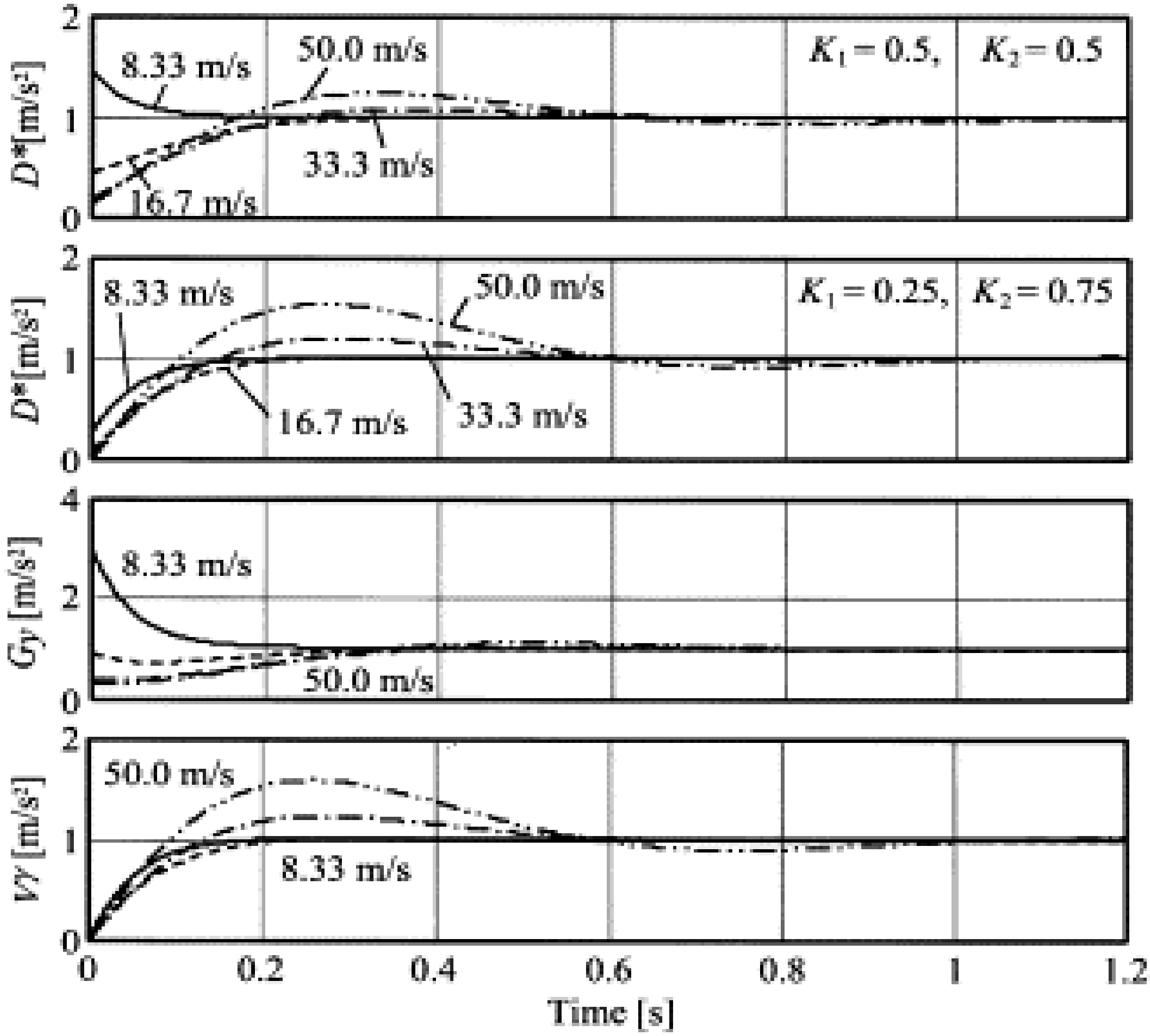


Fig. 8. D∗ step response vs. K_1 (open loop characteristics).

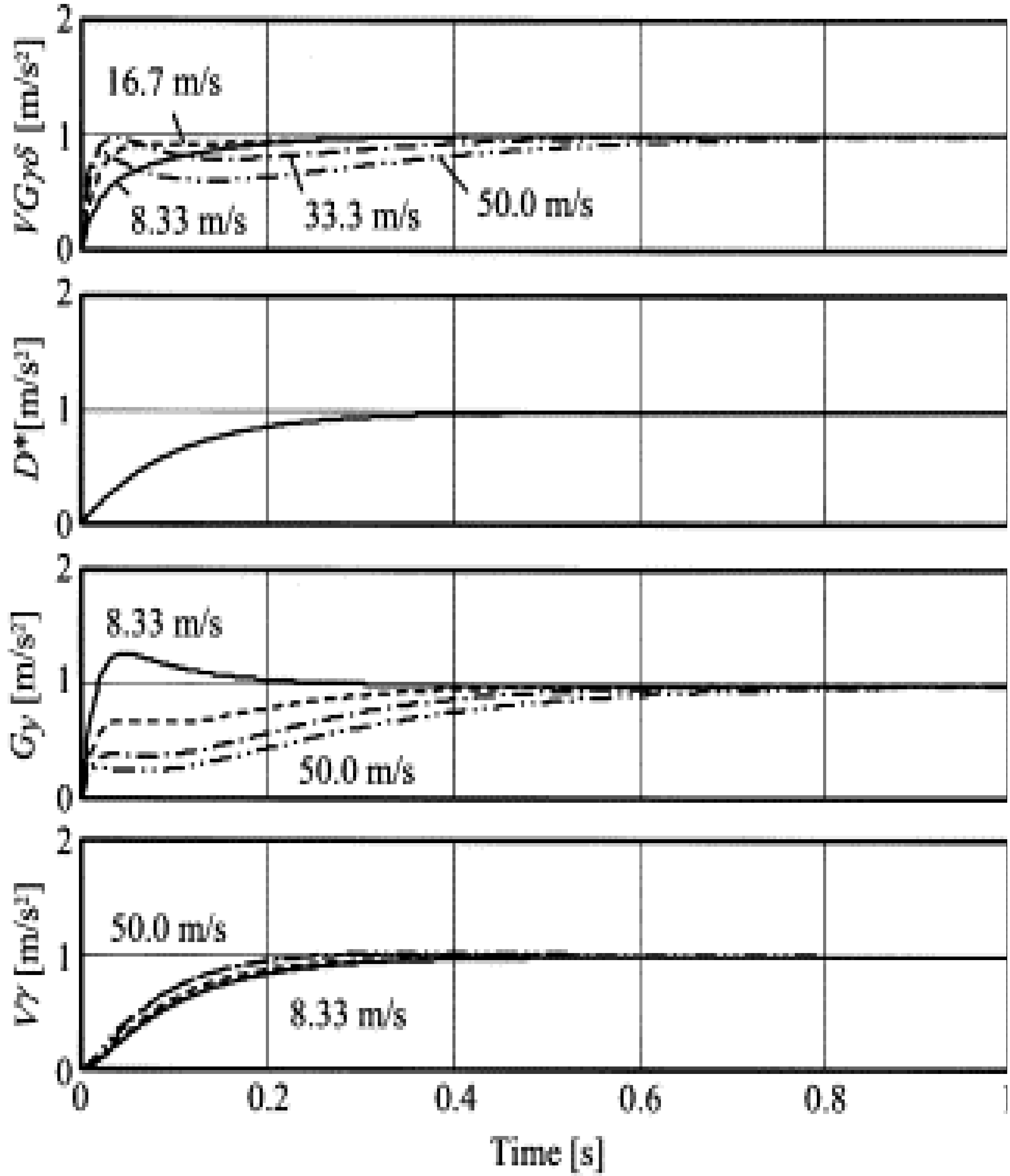
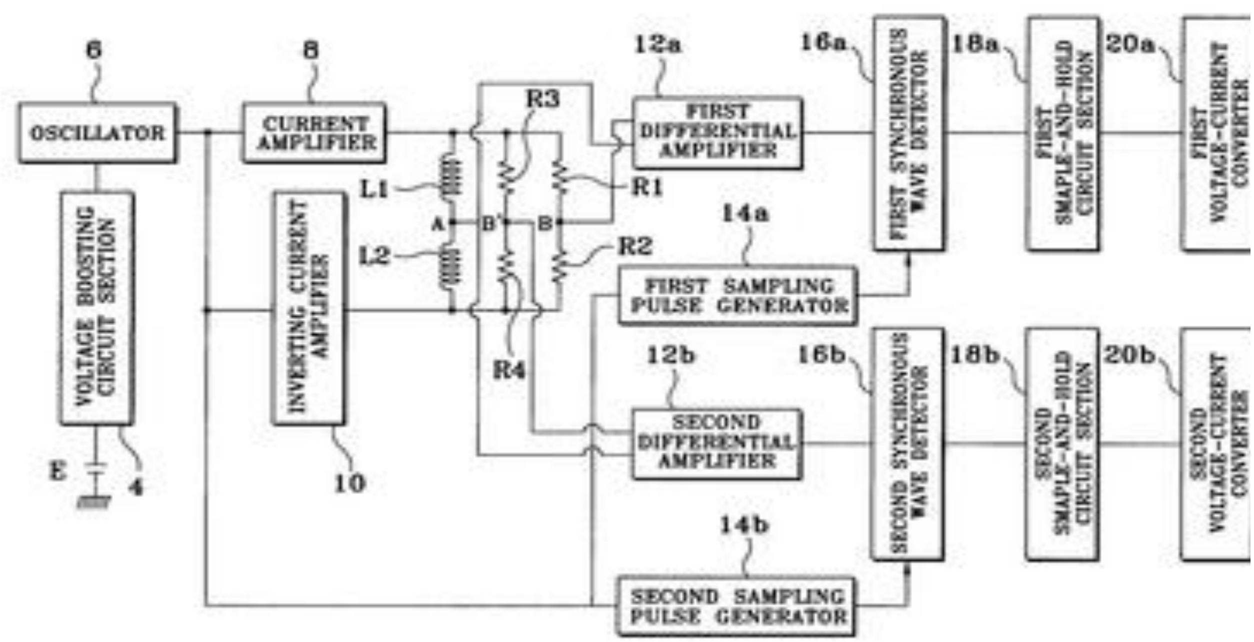


Fig. 9. Vehicle behavior response (K_1: corrected).

Chapter 5

Torque sensor for vehicle steering system

A torque sensor for a vehicle steering system includes a voltage boosting circuit that boosts a voltage supplied from a power source, an oscillator, a current amplifier, an inverting current amplifier, first and second coils, first and second resistors, a differential amplifier, a sampling pulse generator that generates a sampling pulse, a synchronous wave detector that detects the AC voltage output from the first differential amplifier, a first sample-and-hold circuit section that samples and holds the voltage output from the first synchronous wave detector, and a voltage-current converter that converts the voltage output from the first sample-and-hold circuit section into current and outputs the current as a torque signal Ts, thereby stably supplying power to the torque sensor for a steering system.



1. A torque sensor for a vehicle steering system comprising: a voltage boosting circuit that boosts a voltage supplied

from a power source; an oscillator that oscillates with the boosted voltage from the voltage boosting circuit; a current amplifier that outputs a DC voltage and an AC voltage having a phase equal to that of the output voltage of the oscillator; an inverting current amplifier that outputs a DC voltage and an AC voltage having a phase opposite to the phase of the output voltage of the oscillator; first and second coils, each of which is connected to one of an output terminal of the current amplifier and an output terminal of the inverting current amplifier, respectively, the first and second coils connected in series to each other; first and second resistors that are connected in parallel to the first and second coils, the first and second resistors connected in series to each other; a first differential amplifier that is supplied with the voltage of a node between the first and second coils and with the voltage of a node between the first and second resistors, the first differential amplifier differentially amplifying the supplied voltages; a first sampling pulse generator that generates a sampling pulse synchronized with the output voltage of the oscillator; a first synchronous wave detector that detects the AC voltage output from the first differential amplifier in synchronism with the sampling pulse output from the first sampling pulse generator; a first sample-and-hold circuit that samples and holds the voltage output from the first synchronous wave detector; and a first voltage-current converter that converts the voltage output from the first sample-and-hold circuit into current and outputs the current as a torque signal.

2. The torque sensor for a vehicle steering system as defined in claim 1, further comprising: third and fourth resistors that are connected in parallel to the first and second coils, the third and fourth resistors connected in series to each other; a second differential amplifier that is supplied with the voltage of the node between the first and second coils and with the voltage of a node between the third and fourth resistors, the first differential amplifier differentially amplifying the supplied voltages; a second sampling pulse generator that generates a sampling pulse synchronized with the output voltage of the oscillator; a second synchronous wave detector that detects the AC voltage output from the second differential amplifier in synchronism with the sampling pulse output from the second sampling pulse generator; a second sample-and-hold circuit that samples and holds the voltage output from the second synchronous wave detector; and a second voltage-current converter that converts the voltage output from the second sample-and-hold circuit into current and outputs the current as a fail-safe torque signal.

3. The torque sensor for a vehicle steering system as defined in claim 1, wherein an offset voltage corresponding to a boosting multiple of the voltage input to the voltage boosting circuit is supplied to the oscillator.

4. The torque sensor for a vehicle steering system as defined in claim 2, wherein an offset voltage corresponding to a boosting multiple of the voltage input to the voltage boosting circuit is supplied to the oscillator.

5. A torque sensor according to claim 3, further comprising: a temperature compensating coil that receives an output from the oscillator; and a torque detecting coil that receives an inverted output from the oscillator.

Description:

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority of Korean Application No. 10-2004-0093467, filed on Nov. 16, 2004, the disclosure of which is incorporated fully herein by reference.

FIELD OF THE INVENTION

The present invention relates to a torque sensor for a vehicle steering system, and more particularly to a torque sensor for a vehicle steering system which can stably supply power to the torque sensor even when a battery voltage is lowered due to a temporary overload of the vehicle.

BACKGROUND OF THE INVENTION

In general, in an electronic control unit (ECU) of an electrical power steering (hereinafter, referred to as EPS) system of a vehicle, a steering torque resulting from manipulation of a steering wheel by a driver is detected by a torque sensor so as to accomplish the steering operation.

In supplying power to the torque sensor for detecting the steering torque in the conventional EPS system, a battery voltage is supplied to the ECU, the input voltage passes through a regulator in the ECU, and the voltage output from the regulator is used as a source voltage of the torque sensor.

However, when the battery voltage drops lower than a predetermined voltage due to a temporary overload of the vehicle, the source voltage of the torque sensor output from the regulator in the ECU is lower than an allowable range of a rated voltage and thus the torque sensor does not normally work, so that there occurs a problem that the steering operation is not accurately accomplished due to decrease in output of the torque sensor.

SUMMARY OF THE INVENTION

The present invention provides a torque sensor for a vehicle steering system, which comprises a voltage boosting circuit section for boosting a voltage supplied from a power source and uses the boosted voltage as a driving power source of the torque sensor, so as to stably supply power to the torque sensor even when a battery voltage is lowered due to a temporary load of the vehicle.

According to an aspect of the present invention, a torque sensor for a vehicle steering system include a voltage boosting circuit section that boosts a voltage supplied from a power source; an oscillator that oscillates with the boosted voltage from the voltage boosting circuit section; a current amplifier that outputs a DC voltage and an AC voltage having a phase equal to that of the output voltage of the oscillator;an inverting current amplifier that outputs a DC voltage and an AC voltage having a phase opposite to that of the output voltage of the oscillator; first and second coils, each of which is connected to an output terminal of the current amplifier and an output terminal of the inverting current amplifier, respectively, the first and second coils connected in series to each other; first and second resistors that are connected in parallel to the first and second coils, the first and second resistors connected in series to each other; a first differential amplifier that is supplied with the voltage of a node between the first and second coils and the voltage of a node between the first and second resistors, the first differential amplifier differentially amplifying the supplied voltages; a first sampling pulse generator that generates a sampling pulse synchronized with the output voltage of the oscillator; a first synchronous wave detector that detects the AC voltage output from the first differential amplifier in synchronism with the sampling pulse output from the first sampling pulse generator; a first sample-and-hold circuit section that samples and holds the voltage output from the first synchronous wave detector; and a first voltage-current converter that converts the voltage output from the first sample-and-hold circuit section into current and outputs the current as a torque signal Ts.

The torque sensor for a vehicle steering system according to the present invention may further include third and fourth resistors that are connected in parallel to the first and second coils, the third and fourth resistors connected in series to each other; a second differential amplifier that is supplied with the voltage of the node between the first and second coils and the voltage of a node between the third and fourth resistors, the second differential amplifier differentially amplifying the supplied voltages; a second sampling pulse generator that generates a sampling pulse synchronized with the output voltage of the oscillator; a second synchronous wave detector that detects the AC voltage output from the second differential amplifier in synchronism with the sampling pulse output from the second sampling pulse generator; a second sample-and-hold circuit section that samples and holds the voltage output from the second synchronous wave detector; and a second voltage-current converter that converts the voltage output from the second sample-and-hold circuit section into current and outputs the current as a fail-safe torque signal Ts′.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features and advantages of the present invention will become more apparent by describing in detail exemplary embodiments thereof with reference to the attached drawings in which:

FIG. 1 is a block diagram illustrating a torque sensor for a steering system according to the present invention;

FIG. 2 is a waveform diagram illustrating an output voltage of an oscillator according to the present invention;

FIG. 3A is a waveform diagram illustrating an output voltage of a current amplifier according to the present invention;

FIG. 3B is a waveform diagram illustrating an output voltage of an inverting current amplifier according to the present invention;

FIG. 4A is a waveform diagram illustrating an output voltage of a node between first and second coils according to the present invention;

FIG. 4B is a waveform diagram illustrating an output voltage of a node between first and second resistors oscillator according to the present invention;

FIG. 5 is a waveform diagram illustrating output voltages of first and second differential amplifiers according to the present invention;

FIG. 6 is a waveform diagram illustrating output voltages of first and second sampling pulse generators according to the present invention; and

FIG. 7 is a waveform diagram illustrating output voltages of first and second synchronous wave detectors according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, preferred embodiments of the present invention will be described in detail with reference to the accompanying drawings.

A structure of a torque sensor for a vehicle steering system according to the present embodiment will be described with reference to FIG. 1.

As shown in FIG. 1, in the present embodiment, a voltage boosting circuit section **4** boosting a voltage supplied from a power source E is provided so as to stably supply power to the torque sensor for a vehicle steering (EPS) system. Any booster circuit may be employed only if the voltage boosting circuit section **4** can boosting the supplied voltage two or more times.

That is, the torque sensor according to the present embodiment comprises: a voltage boosting circuit section **4** that boosts a voltage supplied from a power source E; an oscillator **6** that is supplied with the boosted voltage from the voltage boosting circuit section **4** and that oscillates; a current amplifier **8** that outputs an offset voltage V_{offset} (DC voltage) and an AC voltage having a phase equal to that of the output voltage of the oscillator **6**; an inverting current amplifier **10** that outputs an offset voltage V_{offset} (DC voltage) and an AC voltage having a phase obtained by delaying the output voltage of the oscillator **6** and inverting the phase thereof by 180°; first and second coils L**1** and L**2** whose both ends are connected to the output terminals of the current amplifier **8** and the inverting current amplifier **10**, respectively, and that are connected in series to each other; first and second resistors R**1** and R**2** that are connected in parallel to the first and second coils L**1** and L**2**and that are connected in series to each other; a first differential amplifier **12***a* that is supplied with the voltage of a node A between the first and second coils L**1** and L**2** and the voltage of a node B between the first and second resistors

R**1** and R**2** and that differentially amplifies the supplied voltages; a first sampling pulse generator **14***a* that generates a sampling pulse synchronized with the output voltage of the oscillator**6**; a first synchronous wave detector **16***a* that detects the AC voltage output from the first differential amplifier **12***a* in synchronism with the sampling pulse output from the first sampling pulse generator **14***a;* a first sample-and-hold circuit section **18***a* that samples and holds the voltage output from the first synchronous wave detector **16***a;* and a first voltage-current converter **20***a* that converts the voltage output from the first sample-and-hold circuit section **18***a* into current and that outputs the current as a torque signal Ts.

On the other hand, the torque sensor according to the present embodiment has a torque detecting structure for fail safe.

That is, the torque sensor further comprises: third and fourth resistors R**3** and R**4** that are connected in parallel to the first and second coils L**1** and L**2** and that are connected in series to each other; a second differential amplifier **12***b* that is supplied with the voltage of the node A between the first and second coils and the voltage of a node B′ between the third and fourth resistors and that differentially amplifies the supplied voltages; a second sampling pulse generator **14***b* that generates a sampling pulse synchronized with the output voltage of the oscillator **6**; a second synchronous wave detector **16***b* that detects the AC voltage output from the second differential amplifier **12***b* in synchronism with the sampling pulse output from the second sampling pulse generator **14***b;* a second sample-and-hold circuit section **18***b*that samples and holds the voltage output from the second synchronous wave detector **16***b;* and a second voltage-current converter **20***b* that converts the voltage output from the second sample-and-hold circuit section **18***b* into current and that outputs the current as a fail-safe torque signal Ts′. Such a torque detecting structure for fail safe is required to accomplish the steering operation using the torque detection signal Ts′ for an auxiliary circuit, when troubles take place in the torque sensor such as when the torque detection signal Ts for a main circuit is reduced, etc.

In the structure according to the present embodiment described above, an offset voltage V_{offset} corresponding to a boosting multiple of the voltage boosting circuit **4** is supplied to the oscillator **6**, the current amplifier **8**, the inverting current amplifier **10**, the first and second differential amplifiers **12***a* and **12***b,* etc.

That is, in the present embodiment, since the boosted voltage is used as a driving power source of the torque sensor, the offset voltage, which is a DC voltage used for the oscillator, the current amplifier, the inverting current amplifier, the first and second differential amplifiers, etc., must be changed to correspond to the boosting multiple.

For example, the offset voltage of 3.5V was used with an operation voltage of 8V for a conventional torque sensor. When the operation voltage is 16V in the voltage boosting circuit structure according to the present embodiment, the offset voltage must be set such that the DC voltage is 6V or more. Incidentally, the offset voltage V_{offset} is generated from a DC power source E applied through an offset voltage circuit structure.

Now, the operation of the torque sensor according to the present embodiment will be described with reference to the drawings.

As shown in FIG. 1, when power is supplied from the power source E, the supplied power is input to the voltage boosting circuit section **4** and the input voltage is boosted. That is, when the input voltage is 8V, the input voltage is boosted to 16V or 24V by the voltage boosting circuit section **4**, and then the boosted voltage is used as the operation voltage for the torque sensor.

In this way, when the boosted voltage is supplied to the oscillator **6**, the oscillator **6** oscillates. That is, as shown in FIG. 2, an oscillating voltage Va biased by the DC voltage V_{offset} supplied to the oscillator **6** is output from the oscillator **6**, and the output oscillating voltage Va is input to the current amplifier **8**, the inverting current amplifier **10**, and the first and second sampling pulse generators **14***a* and **14***b.*

As shown in FIG. 3A, the current amplifier **8** outputs the DC voltage V_{offset} and the AC voltage having a phase equal to that of the voltage output from the oscillator **6**, and as shown in FIG. 3B, the inverting current amplifier **10** outputs the DC voltage V_{offset} and the AC voltage Vb′ obtained by delaying the phase of the voltage input from the oscillator **6** by 180°, at the same time.

On the other hand, a temperature compensating coil L**1** as the first coil and a torque detecting coil L**2** as the second coil are connected between the output terminal of the current amplifier **8** and the output terminal of the inverting current amplifier **10**. At this time, both ends of the temperature compensating coil L**1** and the torque detecting coil L**2** connected in series to each other are supplied with a difference voltage between the AC voltage Vb output from the current amplifier **8** and the AC voltage Vb′ output from the inverting current amplifier **10**. That is, since both ends of the temperature compensating coil L**1** and the torque detecting coil L**2** are supplied with only the DC voltage V_{offset} having the same potential, DC current does not flow through the both ends. Therefore, as shown in FIG. 4A, when the impedance of the torque detecting coil L**2** is greater than the impedance of the temperature compensating coil L**1** (L**2**>L**1**), the AC voltage applied to the node A between the temperature compensating coil L**1** as the first coil and the torque detecting coil L**2** as the second coil is changed in the same way as the AC voltage Vb output from the current amplifier **8**. On the contrary, when the impedance of the torque detecting coil L**2** is smaller than the impedance of the temperature compensating coil L**1** (L**2**<L**1**), the AC voltage applied to the node A is changed in the same way as the AC voltage Vb′ output from the inverting amplifier **10**.

The first and second resistors R**1** and R**2** connected in parallel to the temperature compensating coil L**1** and the torque detecting coil L**2** are connected in series to each other. When the first and second resistors R**1** and R**2** have the same resistance, as shown in FIG. 4B, only the DC voltage V_{offset} is applied to the node B. Incidentally, when the third and fourth R**3** and R**4** for fail safe have the same resistance, the voltage of the node B′ is equal to the voltage of the node B.

The voltages applied to the first differential amplifier **12**_a_ from the node between the first and second coils L**1** and L**2** and the node between the first and second resistors R**1** and R**2** are the DC voltage V_{offset} of the node B between the first and second resistors and the AC voltage (Vb when L**2**>L**1**, and Vb′ when L**1**>L**2**) of the node A between the first and second coils. The voltages are differentially amplified by the first differential amplifier **12**_a_ and then are output to the first synchronous wave detector **16**_a._ The waveform of the voltage output from the first differential amplifier **12**_a_ is shown in FIG. 5.

On the other hand, the first sampling pulse generator **14**_a_ according to the present embodiment generates a sampling pulse s synchronized with the output voltage Va of the oscillator **6** (see FIG. 6). The generated sampling pulse signal is input to the first synchronous wave detector**16**_a_ along with the output voltage of the first differential amplifier **12**_a._

The first synchronous wave detector **16**_a_ receives the signals from the first differential amplifier **12**_a_ and the first sampling pulse generator**14**_a_ and detects the applied AC voltage in synchronism with the sampling pulse. For example, as shown in FIG. 7, when the sampling pulse has a “H” level, the first synchronous wave detector **16**_a_ detects the positive component of the output voltage Vb of the first differential amplifier**12**_a_ and the negative component of the output voltage Vb′. The detected waveform becomes a pulsating waveform as shown in FIG. 7. Incidentally, when the sampling pulse has a “H” level, it can be considered that the steering operation is performed such that the torque increases or decreases from a neutral position to the right side.

The voltage output from the first synchronous wave detector **16**_a_ is held by the first sample-and-hold circuit section **18**_a_ and is output as the torque detecting signal Ts through the first voltage-current converter **20**_a._ The output torque detecting signal is input to an ECU controller (not shown), so that it is possible to secure a steering power by means of drive of a motor corresponding to the torque detecting signal Ts.

On the other hand, operation of the torque sensor for fail safe according to the present embodiment is the same as the operation of the torque sensor for a main circuit described above. That is, as described above, the torque detecting signal Ts′ in the torque detecting structure for fail safe is used for detecting the fail-safe torque in the case where the torque detecting signal Ts for a main circuit is reduced, etc.

As described above, in the torque sensor according to the present invention, since the operating voltage of the torque sensor is boosted for use, it is possible to stably supply power to the torque sensor at any situation. In addition to, small variation in torque can be easily sensed by means of amplitude adjustment of the oscillator. Furthermore, since an amplification ratio of the differential amplifiers can be reduced smaller than the conventional one, it is possible to enhance the signal-to-noise (S/N) ratio.

Therefore, in the torque sensor for a vehicle steering system according to the present invention, it is possible to stably supply power to the torque sensor and to enhance the signal-to-noise (S/N) ratio, even when a battery voltage is lowered due to a temporary overload of the vehicle.

Although the preferred embodiments of the present invention have been described, the present invention is not limited to the preferred embodiments, but may be modified in various forms without departing from the scope of the appended claims. Therefore, it is natural that such modifications belong to the scope of the present invention

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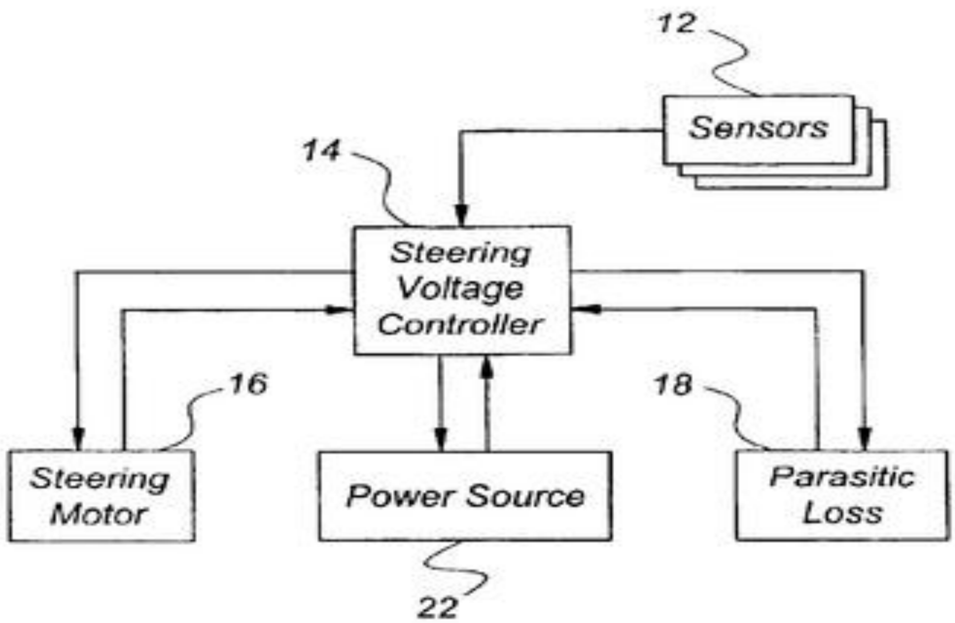
Electrical control system for automotive vehicle having electrically assisted power steering

An electrical system for increasing the amount of voltage available to an electric power steering motor under high demand conditions includes a vehicle speed sensor that ascertains the speed of the vehicle, a steering wheel sensor that ascertains the rotational speed of the vehicle steering wheel, and a steering voltage controller that receives the signals provided by the vehicle speed sensor and the steering wheel sensor and processes these input signals to increase the voltage furnished to the power steering system by causing at least one component that consumes electrical power in the vehicle to reduce power consumption, or by causing a component that produces electrical power to increase power output, or by a combination of reducing power consumption and increasing power production. The present method increases the voltage available to an electric power system steering system by sensing vehicle speed and steering wheel rotational speed, by determining whether these conditions indicate a

demand for greater power steering assist, and by managing electric load and power output to provide more voltage to the electric power steering motor when high demand for power assistance and torque is indicated.



1. An electrical system for an automotive vehicle having an electrically assisted power steering system, said electrical system comprising: a vehicle speed sensor that ascertains the speed of the vehicle and provides a signal indicative thereof; a steering wheel sensor that ascertains the rotational speed of the vehicle steering wheel and provides a signal indicative thereof; at least one component of the vehicle, other than the electrically assisted power steering system, that consumes electrical power; and a steering voltage controller that receives the signals provided by the vehicle speed sensor and the steering wheel sensor, with said controller processing said input signals to produce output signals that control the voltage furnished to the power steering system and to said electric power consuming component.

2. An electrical system according to claim 1, wherein the steering voltage controller, in response to input signals indicating a high demand for power-assisted steering from the vehicle speed sensor and from the steering wheel sensor, produces an output signal that causes said electrical power consuming component to reduce power consumption.

3. An electrical system according to claim 2, wherein the steering voltage controller increases the voltage available to the power steering system when the signals from the vehicle speed sensor and the steering wheel sensor indicate a need for high demand steering assistance.

4. An electrical system according to claim 1, further comprising at least one component of the vehicle that produces electrical power, with said steering voltage controller controlling the operation of said electrical power production component.

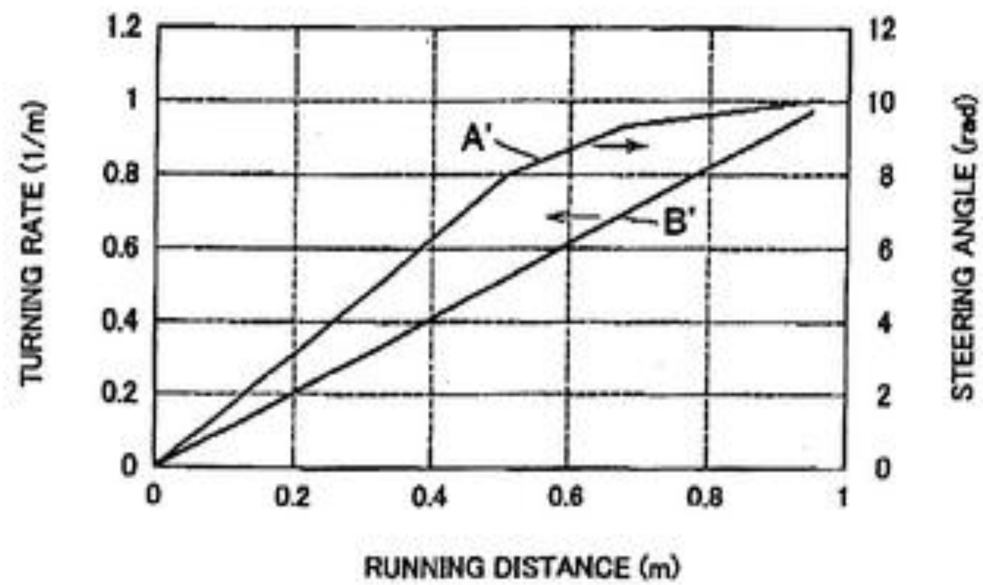
5. An electrical system according to claim 4, wherein the steering voltage controller, in response to signals indicating a high demand for power-assisted steering from the vehicle speed sensor and from the steering wheel sensor, produces an output signal that instructs said electric power production component to increase power production.

6. An electrical system according to claim 5, wherein the steering voltage controller is programmed to furnish the increased power from said electric power production component to the steering system when said input signals from the vehicle speed sensor and the steering wheel sensor indicate a need for high demand steering assistance.

7. An apparatus for regulating voltage supplied to an electric motor assisted steering system in an automotive vehicle comprising: a vehicle speed sensor that ascertains the speed of the vehicle and provides a signal indicative thereof; a steering wheel sensor that ascertains the rotational speed of the vehicle steering wheel and provides a signal indicative thereof; at least one component of the vehicle, other than the electrically assisted power steering system, that consumes electrical power; at least one component of the vehicle that produces electric power; and a steering voltage controller that receives the signals provided by the vehicle speed sensor and the steering wheel sensor and processes said signals so as to determine when demand is high for power-assisted steering, with said controller controlling the voltage furnished to said at least one electrical power consuming component and said at least one electrical power production component, so as to increase the voltage available to the power steering motor when demand is high for power-assisted steering.

Automatic steering control system and method

Abstract:
The steering angle with respect to the running distance is changed by changing the steering angular velocity in accordance with the steering angle and the vehicle speed such that the turning rate has a linear relationship with the moving distance.



1.

An automatic steering control system comprising: a controller which automatically changes a steering angle in accordance with a determined direction change along a moving distance and which controls a steering angular velocity such that a turning rate linearly changes with respect to the moving distance when changing the turning rate.

2. The automatic steering control system according to claim 1, further comprising a vehicle wheel drive device that manipulates a wheel of a vehicle, wherein the controller automatically changes the steering angle of the vehicle wheel drive device such that the vehicle controls thesteering angular velocity of the vehicle wheel drive device such that the turning rate of the vehicle linearly changes with respect to the moving distance of the vehicle when changing the turning rate.

3. The automatic steering control system according to claim 2, wherein the steering angular velocity is changed in proportion to vehicle speed and an inverse of a value obtained by normalizing a change amount of the turning rate with respect to the steering angle by a minimum value of the change amount of the turning rate.

4. The automatic steering control system according to claim 1, wherein the turning rate is determined using an algorithm formulated to linearize the relationship of the steering angle with respect to the moving distance.

5. The automatic steering control system according to claim 1, wherein the controller changes the steering angular velocity in accordance with the moving distance.

6. An automatic steering control method comprising: automatically changing a steering angle in accordance with a determined direction change alone a moving distance; and controlling a steering angular velocity such that a turning rate linearly changes with respect to a moving distance when changing the turning rate.

7. The method according to claim 6, wherein automatically changing the steering angle such that a vehicle controlling the steering angular velocity such that the turning rate of the vehicle linearly changes with respect to the moving distance of the vehicle when changing the turning rate.

8. The method according to claim 7, wherein the steering angular velocity is changed in proportion to vehicle speed and an inverse of a value obtained by normalizing a change amount of the turning rate with respect to the steering angle by a minimum value of the change amount of the turning rate.

9. The method according to claim 6, wherein the turning rate is determined using an algorithm formulated to linearize the relationship of thesteering angle with respect to the moving distance.

10. The method according to claim 6, wherein the steering angular velocity is changed in accordance with the moving distance.

Description:

INCORPORATION BY REFERENCE

The disclosure of Japanese Patent Application No. 2002-080967 filed on Mar. 22, 2002, including the specification, drawings and abstract is incorporated herein by reference in its entity

BACKGROUND OF THE INVENTION

1. Field of Invention

The invention relates to automatic steering control system and method incorporated in a parking assist system or the like.

2. Description of Related Art

There is known an assist system which facilitates parking, such as tandem parking and parallel parking, of a vehicle by an automatic steeringcontrol system assisting a driver in moving the vehicle to a target parking position determined by the driver. For example, such an assist system is disclosed in Japanese Laid-open Patent Publication No. 2001-138941. This system performs a steering control based on a moving route stored in advance as the relationship of the steering angle of the steering wheel wit respect to the moving distance (i.e., running distance) of the vehicle. Also, the system limits the vehicle speed such that the steering angular velocity is maintained within a predetermined range to prevent the vehicle from running at an excessive speed and thus reduce the possibility for the vehicle to deviate from the moving route.

For guiding the vehicle to the target position, it is necessary to move the vehicle to the target portion and make the deviation angle of the vehicle (an angle of the vehicle about its reference direction) equal to a target deviation angle. Since the deviation angle of the vehicle can be obtained from the relationship of change of the turning rate (an inverse of the turning radius) with respect to the moving distance of the vehicle, the moving route, to be stored as aforementioned, can be determined by setting the turning rate with respect to the moving distance of the vehicle.

According to the above-described conventional automatic steering control system, the steering angle is changed at a constant steeringangular velocity with respect to a certain vehicle speed. In vehicles, however, a nonlinear relationship is normally established between thesteering angle of the steering wheel and the turning rate as shown FIG. **1**. Therefore, as shown FIG. 2, when the steering angle is changed at a constant steering angular velocity while the vehicle is moving at a constant vehicle speed (line A), the turning rate nonlinearly changes with respect to the moving distance as represented by the line B. Thus, it is necessary to execute complicated numerical analysis in calculations between the deviation angle and the moving distance, which may be time-consuming in some cases. For example, when the route is corrected during the automatic-steering control, the calculation for setting the route may not be able to catch up with the actual moving speed of the vehicle.

SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide automatic steering control system and method which permit simplification of a route setting process, a route correction process, and the like.

Actually, the above object may be achieved by linearizing the relationship between the steering angle and the turning rate shown in FIG. **1**. However, for maintaining the relationship between the steering angle and the turning rate as shown in FIG. 1 at the neutral steering position, the required operation amount of the steering becomes larger than the value set in the automatic steering control system disclosed in Japanese Laid-open Patent Publication No. 2001-138941, which may cause an operator to have a feeling of unnaturalness. In contrast, if the turning rate obtained when an absolute value of the turning rate is maximum is set equal to the value set in the automatic steering control system disclosed in the above publication, the change amount of the turning rate with respect to changes in the steering angle at or around the neutral steering position becomes large. In this case, therefore, the operator may have a feeling of unnaturalness in operating thesteering, and may have a difficulty in making minor course changes which are necessary, for example, for making a lane change on a high way. Consequently, the above-described arrangements are considered to be impracticable.

In view of the above situation, an automatic steering control system according to a first aspect of the invention is arranged to control thesteering angular velocity such that the turning rate linearly changes with respect to the moving distance when changing the turning rate.

When the steering angular velocity is adjusted at the time of changing the taming rate such that the tug rate linearly changes with respect to the moving distance, it permits mutual conversions to be analytically performed between the deviation angle and its moving distance. This eliminates the necessity of executing complicated numerical analysis, thus simplifying the calculation processes. Furthermore, since analytical calculations are executed, accumulation of errors which may take place in numerical analysis is not caused, whereby the calculation speed can increase and further calculation accuracy can be achieved. Therefore, for example, a vehicle can be reliably moved along a set route and the steering can be effectively operated up to the maximum steering angle during the automatic steering control.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and further objects, features and advantages of the invention will become apparent from the following description of preferred embodiments with reference to the accompanying drawings, wherein like numerals are used to represent like elements and wherein:

FIG. 1 is a graph showing the relationship between the steering angle and the turning rate which is normally established in vehicles;

FIG. 2 is a graph showing the relationship among the moving distance, the steering angle, and the turning rate, which is established in theautomatic steering control system disclosed in Japanese Laid-open Patent Publication No. 2001-138941;

FIG. 3 is a view schematically showing the configuration of an automatic steering control system according to one embodiment of the invention;

FIG. 4 is a graph showing the relationship among the moving distance, the steering angle, and the turning rate, which is established in theautomatic steering control system according to the embodiment of the invention; and

FIG. 5 is a graph showing the relationship among the moving distance, the steering angular velocity, and the steering angle, which is established in the automatic steering control system according to the embodiment of the invention when the vehicle runs at different speeds.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Hereafter, a preferred embodiment of the invention will be explained with reference to the accompanying drawings. In order to facilitate understanding of the explanation, the same reference numerals and characters will, as much as possible, be assigned to the same components in each drawing, and overlapping explanations will be omitted.

FIG. 3 is a block diagram schematically showing the configuration of an automatic steering control system **10** according to one embodiment of the invention, which is used in a vehicle. Referring to FIG. 3, the automatic steering control system **10** includes an ECU (Electronic Control Unit) **1**, a drive motor **4**, and a displacement sensor **5**. The ECU **1** includes a CPU, a ROM, a RAM, an input signal circuit, an output signal circuit, a power supply circuit, and so on, and is adapted to control the operation of the automatic steering control system **10**. The drive motor**4** is disposed between a steering wheel **2** and a steering gear **3** and serves also as a power steering device. The displacement sensor **5** is arranged to detect the displacement amount of the steering. Also, the ECU I receives signals output from the displacement sensor **5** and a vehicle speed sensor **6** and is adapted to control the driving of the drive motor **4**. Here, it is to be noted that the steering wheel **2** can, in this embodiment, be regarded as “a vehicle wheel drive device” of the invention

The relationship established between the steering angle of the steering wheel **2** and the tug rate of the vehicle is represented in the graph of FIG. **1**. Referring to the graph, when the steering angle is φ and the turning rate is γ, their relationship is re ted as follows:

$\gamma=f(\varphi)$ (1)

Then, the relationship between the moving distance (i.e., running distance) p of the vehicle and the turning rate γ established when thesteering is operated to a target steering angle at a constant steering angular velocity ω per unit distance is represented as follows:

$\gamma=f(\omega\times p)$ (2)

The line B of FIG. 2 corresponds to this relationship. Then, the deviation angle θ of the vehicle is obtained by the following expression: $\theta=\int_0^p \gamma \, dp$ (3)

As aforementioned, since the turning rate γ has a nonlinear relationship with respect to the moving distance, the expression (3) can not be analytically solved. Thus, a numerical integration needs to be executed to solve it.

To this end, the automatic steering control system **10** of the embodiment incorporates an algorithm formulated to linearize the relationship of the steering angle φ with respect to the moving distance p. That is, the change amount Δγ of the turning rate γ when the steering angle φ has slightly changed by Δφ from the expression (1) is represented as follows: $\Delta\gamma=\frac{d}{d\phi}f(\phi)\Delta\phi$ (4)

Then, the minimum value of the inclination of the change in γ of the expression (4) is represented as “Jmin” as follows: $J_{min}=\min\left[\frac{d}{d\phi}f(\phi)\right]$ (5)

Subsequently, the inclination of the change in γ is normalized by Jmin to obtain m (φ). $m(\phi)=\frac{1}{J_{min}}\frac{d}{d\phi}f(\phi)$ (6)

When the values are set in the above manner, the change amount of the turning rate when the steering is turned by a certain steering angle φ is m (φ) times of Jmin. The m (φ) is changed according to the steering angle φ.
$\Delta\gamma = m(\varphi) J_{min} \Delta\varphi$ (7)

Hereinafter, m (φ) will be referred to as “a gradient ratio.”

Here, the steering angular velocity ω is not always constant but is changed in accordance with the steering angle φ and the vehicle speedusing the following expression: $\omega=\frac{\alpha}{m(\phi)}V$ (8)

Here, α is a constant. That is, the steering angular velocity ω changes in proportion to the vehicle speed V and an inverse of the gradient ratio m (φ). Assuming that the maximum vehicle speed which the automatic steering control system is able to catch up with is represented as “Vmax” and the maximum steering angular velocity ω corresponding to the maximum vehicle speed Vmax is represented as “ωmax”, α is preferably set to ωmax/Vmax when m (ω) is 1.

Thus, the increase amount of the steering angle φ according to a change in the moving distance while increasing the steering angle is represented as follows: $\Delta\phi=\frac{\alpha}{m(\phi)}\Delta p$ (9)
Then, by assigning the expression (9) to the expression (7), it becomes: $\Delta\gamma=m(\phi)J_{min}\frac{\alpha}{m(\phi)}\Delta p=J_{min}\,\alpha\,\Delta p$ (10)
Thus, the relationship between γ and p is linearized.

More specifically, the ECU **1** determines the operation amount of the steering wheel **2**, to be driven by the drive motor **4**, per unit time by executing the expression (8) using the displacement amount of the steering wheel **2** (which corresponds to the steering angle φ) detected by the displacement sensor **5** and the vehicle speed V indicated by the signal output from the vehicle sensor **6.** The ECU I then controls the drive motor **4** in accordance with the determined operation amount of the steering wheel **2**.

FIG. 4 is a graph showing changes in the steering angle φ and the turning rate γ with respect to the moving distance p of the vehicle which is running by the automatic steering control system when “α=ωmax/Vmax” is set according to the expression (8). As the steering angle φ, represented by the line A′, increases, its change amount with respect to the moving distance p reduces in proportion to an inverse of the gradient ratio m (φ). On the other hand, the turning rate γ, represented by the line B′, linearly changes with respect to the moving distance p.

FIG. 5 is a graph for comparing changes in the steering angular velocity ω and the steering angle φ with respect to the moving distance p when the vehicle moves at a constant vehicle speed Vo, a speed two times faster than Vo, and a speed three times faster than Vo. According to the expression (8), the steering angular velocity ω changes in proportion to the vehicle speed V. Thus, the change amount of the steeringangle per unit distance is always constant, rather than changing in accordance with the vehicle speed. Therefore, the steering angle, represented by the line C, changes in the same manner in any case. Accordingly, the turning rate can be linearized with respect to the moving distance p independent of the vehicle speed.

With the relationship of the turning rate γ with respect to the moving distance p which has been linearized as described above, the deviation angle θ is obtained by the following expression after solving the following expression (3) analytically. θ=J□ □min□ □α2□p2(11)

Conversely, it is also possible to obtain the moving distance p from a necessary deviation angle θ. According to the embodiment, therefore, the necessity of executing complicated numerical analysis in parking assist systems, running assist systems, and the like, which perform anautomatic steering control, can be eliminated, which makes it possible to simplify the construction of such systems. According to the embodiment, moreover, since analytical calculations are executed, accumulation of errors which may take place in numerical analysis is not caused, whereby the route calculation speed can increase and further calculation accuracy can be achieved.

As described above, since a linear relationship is established between the turning rate and the moving distance in the automatic steeringcontrol system of the embodiment, the calculations between those values can be analytically executed and be simplified, which assures an increased route calculation speed as well as improved calculation accuracy.

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