

Development of the Next-generation Steering System (Development of the Twin Lever Steering System)

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ABSTRACT

With the objective of establishing the ultimate steering operation system for drivers, we developed, based on bioengineering considerations, the Twin Lever Steering (TLS) system which mimicks the bi-articular muscles, as shown in Fig. 1. The bioengineering advantages are as follows: (1) force can be exerted more easily, (2) the steering can be accomplished quickly, (3) the positioning can be done accurately, and (4) the burden on the driver can be reduced (less fatigue). The advantages of the vehicle in terms of its motion are as follows: (1) the line-traceability is improved, (2) the drift control is improved, (3) the lane-change capability is improved, and (4) the lap time and stability are improved. We would like to report on these advantages of the TLS system from a bioengineering standpoint, and also describe the results of some verification test results obtained from vehicles equipped with this new steering system.

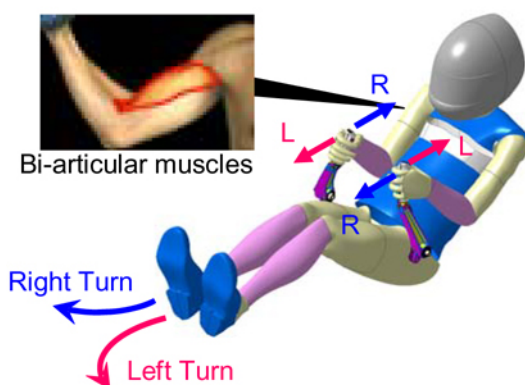


Fig. 1.

INTRODUCTION

In the field of four-wheel vehicles, the possibility of constructing a new steering system is now quickly gaining popularity through the introduction of new technologies, such as by-wire operation, active control, etc. In order to create a vehicle which, regardless of the driving experience or the age of the driver, can move just as the driver desires, controlled easily and smoothly, it is critically important to create a steering system best suited to human use. To do this, a key aspect is optimizing the motions of the driver's upper limbs. In recent years, it has gradually become clear that the bi-articular muscles are crucial to motion control of the upper limbs. Research on motion control is being actively promoted, particularly control achieved in a coordinated manner between mono-articular and bi-articular muscles^{1), 2)}.

With this background, we developed a TLS system for four-wheel vehicles based on theory of muscular cooperative control, and verified the feasibility of this system with respect to its effects and vehicle-layout properties on the assumption that it is mounted on a race car.

MAIN SECTION

1. CHARACTERISTICS OF THE HUMAN AS A DRIVER ^{3),4,5,6,-7)}

1.1. Theory of coordinated control exerted by muscles

The basic motions of the upper limbs are, as shown in Fig. 2, made in a 2-dimensional plane by the shoulder joint (J_1), elbow joint (J_2) and wrist joint (J_3). According to the theory on the coordinated control exerted by muscles, the motions of the upper limb made by two joints (J_1 and J_2) with two degrees of freedom can be modeled using six muscles in three

pairs ($e_1, e_2, e_3; f_1, f_2, f_3$), as shown in Fig. 3; the theory also clarifies the relationship between the force generated by each muscle and the distribution of the output force exerted by the wrist joint (J_3). Also, the distribution of the output force delivered by the wrist joint can be approximated to a hexagon. When the wrist joint (J_3) moves back and forth in a straight line (y-axis) connecting the shoulder joint (J_1) and the wrist joint (J_3), the muscles which exert the output force, e_2 and f_2 , are directly involved in the motion. On the other hand, when the wrist joint (J_3) moves up and down, the muscles which exert the output force, e_1, e_3, f_1 and f_3 , are not directly involved in the motion. In other words, the steering operation in the back-and-forth direction implies a closer relationship between the relevant output muscles and the direction of motion, as compared with that in the up-and-down direction: so, it is possible to improve the motion control properties.

In this study, as shown in Fig. 2, we roughly divided the steering operation into two components: i.e., the operation in the normal (back-and-forth) direction and that in the tangential (up-and-down) direction. This division was made in terms of a circle centered on the shoulder joint and with the radius (r) equal to the distance between the shoulder joint and the wrist joint. Then, we compared the data to verify the operability.

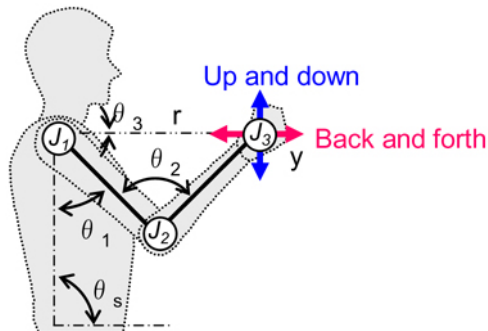


Fig. 2. Motion location of the human arm

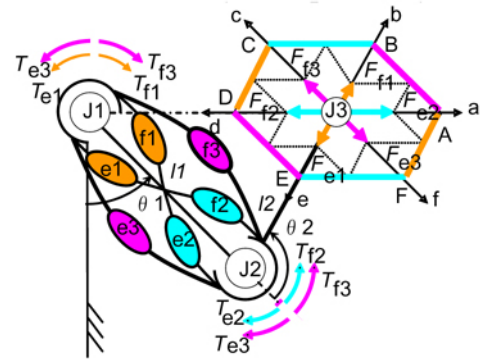


Fig. 3. Fundamental muscular arrangement of the human arm

1.2. Active movements

1.2.1. Characteristics of the output force

Fig. 4 shows the directional dependency of the maximum output force exerted during the movement made by the wrist joint, as measured in one subject. Also, Fig. 4 illustrates that the maximum output force of the wrist joint (J_3) motion is achieved when the elbow joint angle (θ_2) is 90° or 135° . The distance between each point and the center of the circle represents the maximum output force available in the direction from the center of the circle toward the point in question, while the distance equal to the radius of the circle corresponds to an output force of 500 N. Although Fig. 4 shows only two elbow joint angles (θ_2), 90° and 135° , to describe the representative driving positions of the driver, when the elbow joint angle (θ_2) exceeds approximately 60° , a larger force can be exerted more easily in the back-and-forth direction than in the up-and-down direction.

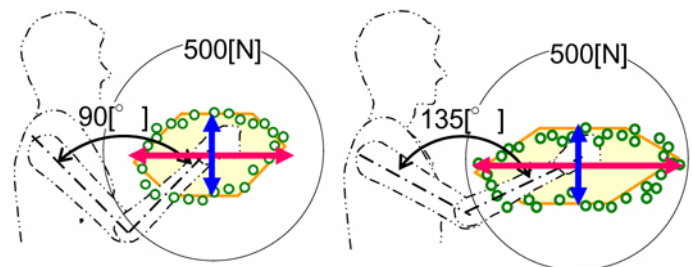


Fig. 4. Comparison of the output force

1.2.2. Characteristics of the output velocity

As for the characteristics of the output velocity, we introduced a new way of thinking about operability^{8), 9)}; we asked one subject to move, starting from the basic posture, his wrist joint back and forth as quickly as possible and took measurements of the velocity; we did the same thing for the up-and-down motion. The term “operability” is often used when kinematically evaluating the operational capability of a

robot or manipulator, and this method is employed for evaluations using an operability ellipse (for a velocity distribution) as an index, computed from the relationship between the angular velocity of each joint and the velocity generated by the wrist joint. We took as the basic arm posture the arm posture where the elbow joint angle, θ_2 , is 90° (i.e., when operability reaches its maximum), and we took measurements of the wrist joint velocity at five measurement points within the interval of ± 100 mm from the basic arm posture, in the back-and-forth as well as the up-and-down direction.

Fig. 5 shows the relationship between the wrist joint velocity and the wrist position as obtained against the basic arm posture at the elbow joint angle, θ_2 , of $80^\circ \sim 110^\circ$, and the seat back angle (chest angle), θ_s , of 90° . Motion velocities in the back-and-forth direction are greater than those in the up-and-down direction. Fig. 6 shows the relationship between the wrist joint velocity and the seat back angle (chest angle), θ_s , as obtained against the basic arm posture at the elbow joint angle, θ_2 , of $80^\circ \sim 110^\circ$. As the seat back angle increased, the velocity in the back-and-forth direction gradually decreased, while the velocity in the up-and-down direction suddenly decreased after reaching its peak ($\theta_s = 100^\circ$); namely, the operation in the back-and-forth direction had a wider allowable range for the seat back angle (chest angle) as compared with that in the up-and-down direction.

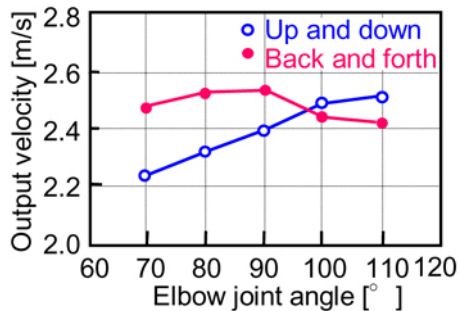


Fig. 5. Comparison of the output velocity ($\theta_s=90\text{deg}$)

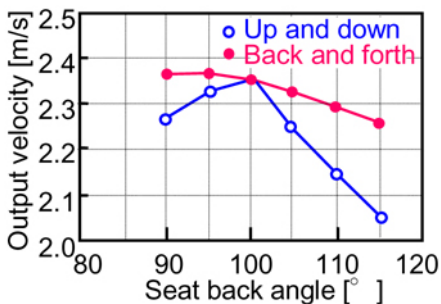


Fig. 6. Comparison of the output velocity ($\theta_s=90\text{deg}-120\text{deg}$)

1.2.3. Characteristics of the position control

Fig. 7 shows the tracking test results obtained by means of a simulator. The right-hand portion of Fig. 7 shows a comparison of the deviations between the steering wheel and the TLS, as obtained in two different cycles. The deviations in operation in the back-and-forth direction are smaller than those in the up-and-down direction; namely, better tracking of the target position can be obtained, and there is little deterioration in performance as time passes.

1.2.4. Characteristics of muscular fatigue

Fig. 8 shows a comparison between the steering wheel and the TLS of the changes in the myoelectric potential obtained at various positions of the operator (shoulder muscles, elbow muscles and bi-articular muscles). Smaller changes were observed in the electromyography with the TLS than with the steering wheel, indicating a smaller degree of fatigue in the operator (i.e., the driver). Namely, the operator will feel less fatigue when operating the TLS than when operating the steering wheel.

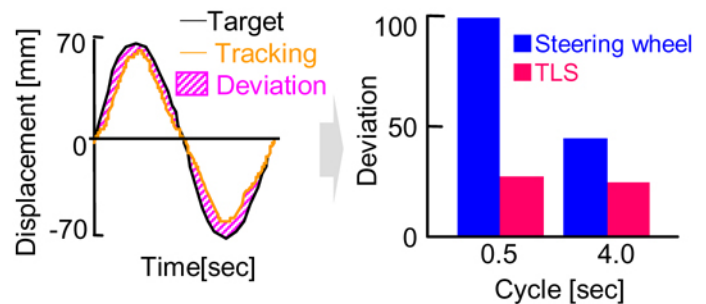


Fig. 7. Tracking test result of the simulator

	Steering wheel		TLS	
	Start	30 min.after	Start	30 min.after
Shoulder				
Elbow				
Bi-articular				

Fig. 8. Electromyography of the tracking test

2. PROTOTYPE VEHICLES

We designed and built several prototype vehicles equipped with the TLS system, in which back-and-forth operations were carried out along a straight line connecting the shoulder and the wrist. Regarding the steering mechanism of these prototype vehicles, the steering wheel and the operation grip are linked mechanically.



Three kinds of vehicles equipped with the TLS system, based on race cars, are shown in [Figs. 9, 10 and 11](#).

2.1. Racing kart-based vehicle

[Fig.9](#) shows a TLS prototype vehicle built based on the racing go-kart (hereinafter called the “Kart” vehicle), and it is equipped with a link-type TLS system.

2.2. Formula Dream-based vehicle

[Fig.10](#) shows a prototype vehicle built based on the Formula Dream (hereinafter called “FD vehicle”), and it is equipped with a sequential shift.

2.3. Formula 1-based vehicle

[Fig.11](#) shows a prototype vehicle built based on the Formula 1 (hereafter referred to as the “F1 vehicle”), with the shift button, clutch lever and various switches all mounted on the TLS grip.



Fig. 9. Racing Kart-based prototype vehicle

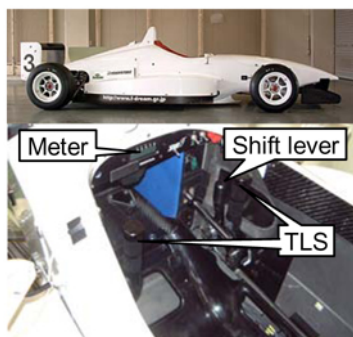


Fig. 10. Formula Dream-based prototype vehicle



Fig. 11. Formula 1-based prototype vehicle

3. CHARACTERISTICS OF THE VEHICLE DYNAMICS

3.1. Basic turning characteristics

We evaluated characteristics of the vehicle dynamic of TLS prototype vehicles through cruising tests.

[Fig.12](#) shows the cruising test data obtained for the F1 vehicle, including the brake pressure and steering angle needed for both the vehicle equipped with a steering wheel and that equipped with the TLS to turn around a corner (R 100); it also shows the time gap computed by subtracting the time required by the TLS vehicle from that required by the steering-wheel vehicle. As shown in [Fig.12](#), as compared with the steering-wheel vehicle, the TLS vehicle takes approximately half of the distance and time before the steering angle is determined after braking has begun.

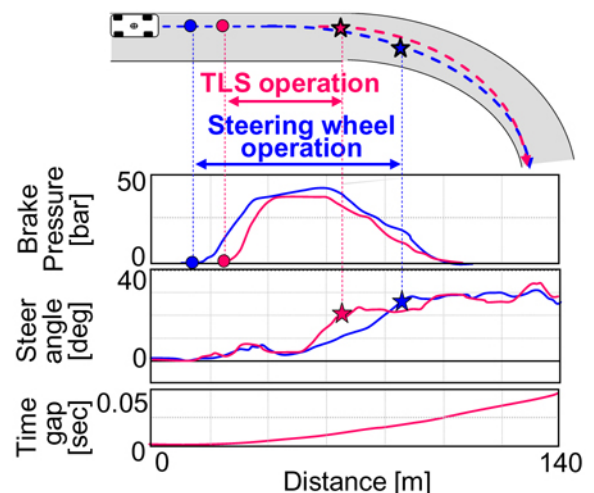


Fig. 12. Tning test results

3.1.1. Turning locus (trace line)

In order to compare the turning performance, we simulated the trace line. Here, the trace line simulation is as follows: Maximum turning performance = Demonstration of the maximum centrifugal force.