Inverse Dynamics Analysis of Driver-Seat-Steering System using Multibody Human Model

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Abstract

In this study, we deal with a driver-seat-steering system as shown in Figure 1. Depending on various situations, a driver controls a vehicle with skillfully contracting his/her own muscles around skeletal bones. Muscle forces acting in cooperation generate joint torques and these are transmitted to the steering wheel and the pedals of the vehicle. At the same time, seat reaction forces and inertial forces due to vehicle dynamics are exerted upon the driver's body. In that context, the driver in a vehicle can be regarded as a multibody system subjected to various external forces.

To investigate driver's motion, many researchers take a biomechanical and neuromuscular modeling approach such as [1]. In this study, we take an experiment-based and inverse dynamics approach shown in Figure 2. The movements of the driver are measured by a motion capture consisting of 14 cameras. Steering forces are measured by a steering wheel unit with six axis transducers on the spokes. To extract the net force exerted by the driver's hands, inertia forces due to gravity, rotation of the steering wheel, and vehicle dynamics are all compensated. Pedaling forces are measured in the same way as the steering forces. Pressure distributions between the driver and the seat are measured by capacitive sensor mats. Equivalent force/torque are calculated based on measured pressure and the shape of the seat surface. The interactions among the driver, the seat and the steering wheel are analyzed with the following equation of motion describing the driver, which has 23 rigid bodies and a total of 64 degrees of freedom.

$$\begin{bmatrix} M & G^T \\ G & 0 \end{bmatrix} \begin{bmatrix} \ddot{q} \\ \lambda \end{bmatrix} = \begin{bmatrix} Q - g - h - J_e^T F_e \\ \gamma \end{bmatrix} \tag{1}$$

where M is the inertia tensor of the driver's body. q is the vector of the generalized coordinate consisting of degree of freedom of the driver's body. G is the constraint Jacobian. λ is the constraint force and the Lagrange multiplier. Q is the generalized force. g is the gravity term. h is the centrifugal and Coliolis force. γ is the term related to derivative of the constraints. J_e is the Jacobian to contact points between the driver and the vehicle. F_e is the contact force. In this study, relative coordinates are used to describe the equation of motion of the driver's body [2]. Successively substituting measured motions q, $\dot{q}$, $\ddot{q}$ and the contact forces F_e into formulated Equation (1), generalized force Q is calculated by using a projection method [3] as

$$PM\ddot{q} = P(Q - g - h - J_e^T F_e) \tag{2}$$

where P is the matrix that describes the projection of G onto the null space.

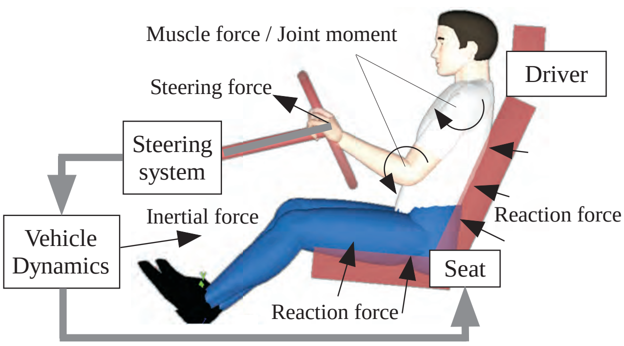

Figure 1: A driver-seat-steering system

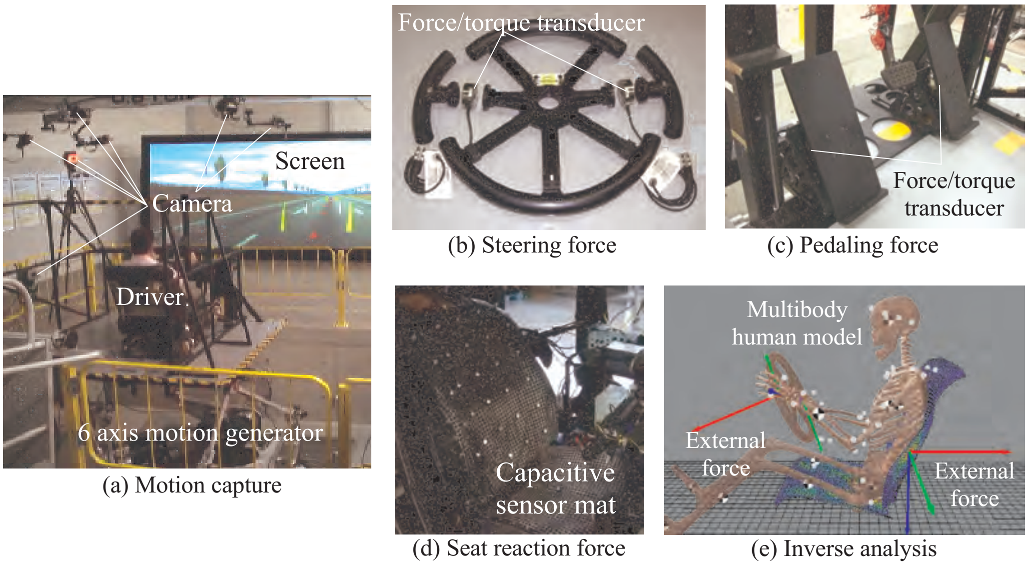

Figure 2: Overview of the inverse analysis of driver-seat-steering system

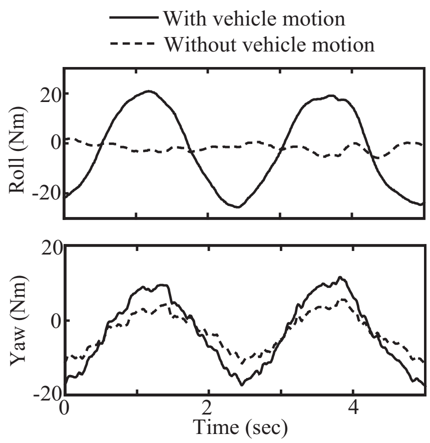

Figure 3: Estimated lumbosacral joint torque in slalom maneuver

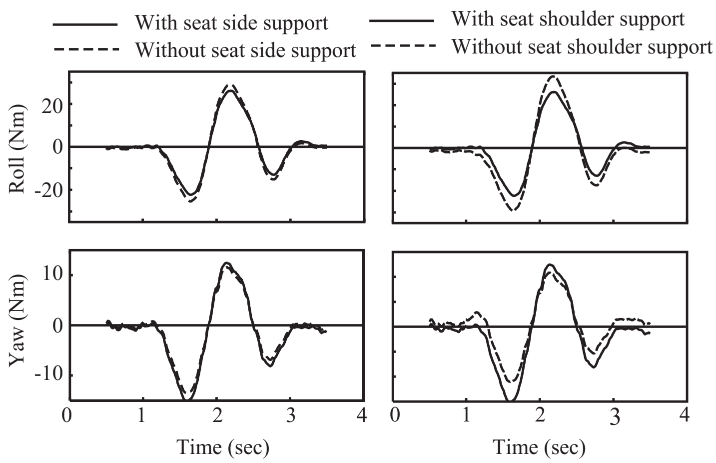

Figure 4: Estimated lumbosacral joint torque in lane change

A skillful driver's slalom and lane change maneuvers (lateral acceleration $\approx$ $2.0m/s^2$) were measured under a six-axis motion generator environment. To investigate effects of vehicle motion, seat side support, and seat shoulder support on the lumbosacral joint torque, the inverse dynamics were executed with scaling the measured vehicle motion and seat contact force (Figure 3 and 4). The results suggest that the joint torque in yaw direction is used dominantly for turning the steering wheel, and that shoulder support force might have more effect on the steering wheel operation than side support force.

The proposed inverse analysis would give significant insights for biomechanical, neuromuscular driver modeling and control theoretic driver modeling. In addition, it can be helpful in designing seat and steering characteristics from a mechanical point of view.

References

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