ANALYSIS AND IDENTIFICATION OF DRIVER POSTURE AND STATE OF MIND

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ABSTRACT

Most of the traffic accidents are because of driver distraction that may be as a result of engagement in a secondary activity (such as texting, eating), or the driver's state of mind (sleepy, tired, angry, nervous, etc.). There are many studies available in the literature about determining and monitoring the driver attention. These studies can be classified into five different types of measures: 1) subjective report measures; 2) driver biological measures; 3) driver physical measures; 4) driving performance measures; and 5) hybrid measures. The first 2 approach is not suitable for real-time applications. Physical measures are related to driver posture and can be analyzed real-time by using appropriate sensors. Almost all academic studies and commercial products on some luxury intelligent cars on the market use vision based systems for this purpose. Furthermore, researches are ongoing to improve the algorithms that interpret the driver‘s physical measures. On the other hand, driver performance can be interpreted using the variables collected in intelligent cars by suitable algorithms. Some commercial products use the history of steering wheel torque and position variables to identify the driver distraction. With continually improving technology, sensors are evolving both in terms of precision and price. An example is the torque sensor which started to be used to measure the torque applied by the driver in order to determine the level of assistance of the steering system. However, 6 axes torque/force sensors are highly expensive to be used in the market. On the other hand, once they become cheap and easily available, they can be used to interpret both the driver posture and the state of mind as the steering wheel is one of the most critical parts of the car where the driver interacts with. For instance, if the driver is maneuvering with single hand, the position of the driver hand can be determined analytically from the torques and forces that the driver exerts to the steering wheel. Hence, interpreting the driver’s posture as well as state of mind may become possible using the hand position and the torques and forces that the driver exerts. In this study, a steering wheel jig is designed and produced equipped with a 6 axes torque/force sensor and an encoder in order to develop algorithms to determine the driver’s attention.

Keywords: *Driver Posture, Steering Wheel, Driver Inattention, Driver Status*

INTRODUCTION

Driver inattention constitutes a major cause of traffic crashes. According to 2018 research [1] of TÜİK there are over 1.2 million traffic accidents in Turkey and 89% of the accidents are caused because of driver inattention. In an effort to assist drivers in the driving process and reduce the degree of crashes a number of intelligent driver systems have been introduced. Such systems are typically designed to provide assistance or warnings to drivers. Recognizing the driver’s activity automatically during driving has become the most significant task of this systems. Moreover characterizing driver’s behavior is the most challenging aspect. Various studies have shown the possibility of state of mind detection by means of vision based measures. These methods generally capture the driver’s eye state using computer vision systems. One of the studies about vision based system is a robust eye detection algorithm [2] that is introduced to address the problems caused by changes in illumination and driver posture. Another study is an Adaboost improved [3] that is used with CART to detect face, and then the centroid of face is calculated to monitoring the head gesture. They also use an Active Appearance Model to detect eye’s open and close status. Drowsy driver detection system [4] has also been developed, using video processing analyzing eyes blinking concepts for measuring eyes closure duration and head posture estimation to verify the driver vigilance state. Another method for capturing the body posture of a driver is a low-cost infrared depth sensor [5]. The findings of this method provide significant regarding which body movements may hide unsafe situations while performing a driving maneuver. The results of vision based methods show that determining of eye state and head posture are not enough for making a real-time accurate decision of state of mind.

Also there are some studies about biological measure methods for state of mind detection. A posture recognition technique [6] based on a high resolution pressure sensor integrated invisibly and unobtrusively into the fabric of the driver seat has been develop, taking the pelvic bone distance as a biometric trait. The proposed driver identification

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technique is implicit and thus not reliant to attention, it is continuously in operation while seated, and requires no active person cooperation. There is also a study about basic properties of vehicle interior [7]. They particularly emphasized car seat design, upholstery fabrics and passenger safety. On the other hand, the driver biological measure methods are not suitable for real time applications.

Furthermore, researches are ongoing to improve the algorithms that interpret the driver‘s physical measures real time. It is known that while driving humans actively adjust their arm postures and hand forces by perceiving the changes in the reaction torque from the steering wheel according to vehicle speed and load conditions. With detection of these relations between human and steering wheel by suitable algorithms, driver performance can be interpreted. One of the studies about the relation between human and steering wheel is an active-steering control method [8] that uses human hand impedance properties. In this study, the dynamic properties of a steering device manipulated by the upper limbs are automatically regulated according to the damping coefficient of the human-steering system. The human-steering system is discussed using a rotational spring-mass-damper system. Thus, in the present study we aim to develop a real-time analysis of driver and steering wheel relation while recognizing the driver’s activity automatically during driving and classifying those behavior.

THEORY

Fig. 1a shows a schematic view of the steering system developed in this study. The steering system comprises a 6 axes ATI torque/force sensor attached to the steering-wheel; a rotary encoder attached at the end of the jig and a NI USB data acquisition card (DAQ) for reading the values taken from sensors and making the analysis of driver posture. With the system below, the torque and force values applied and the hand position into steering wheel are analytically calculated with some assumptions.

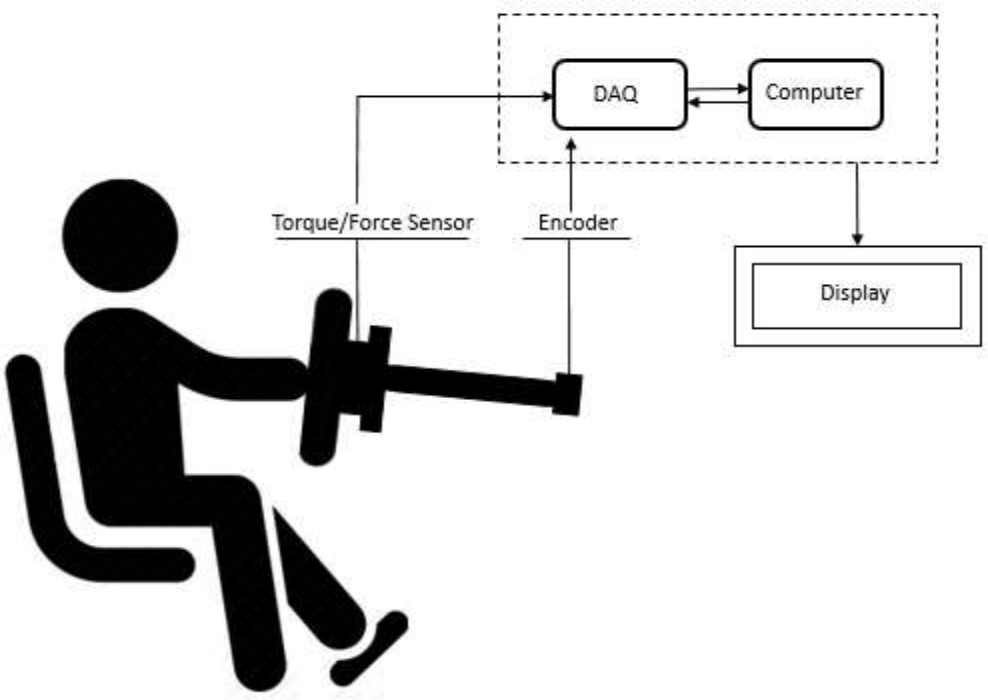


Figure 1a. Experimental system

Fig. 1b shows a free-body diagram of a steering-wheel driven by two-hands. The free-body diagram is consist of origin, left-hand and right-hand frames. Frame is a set of four vectors giving position and orientation information [9]. At the origin of the body diagram in frame 0, $\{X_0, Y_0, Z_0\}$ are supposed to be first origin coordinates of steering wheel where $\{X_{lh}, Y_{lh}, Z_{lh}\}$ are the coordinates of left-hand; $\{X_{rh}, Y_{rh}, Z_{rh}\}$ are the coordinates of right hand with respect to

right-hand coordinate rules [10], and θ_{sw} is the angle of the steering wheel which is zero at the origin coordinate frame and is measured with encoder as shown in Fig. 1a. While driving, θ_{sw} is changed according to driver actions, so new coordinates of steering wheel at frame 1 are represent with $\{X_1, Y_1\ Z_1\}$. In this study, the force and torque values at frame 1 are measured with a sensor, where Phi_1 is the skew-symmetric matrix that shows the measured values:

$$Phi_1 = \begin{bmatrix} 0 & -\mathrm{mz} & \mathrm{my} & \mathrm{fx} \\ \mathrm{mz} & 0 & -\mathrm{mx} & \mathrm{fy} \\ -\mathrm{my} & \mathrm{mx} & 0 & \mathrm{fz} \\ -\mathrm{fx} & -\mathrm{fy} & -\mathrm{fz} & 0 \end{bmatrix} \tag{1}$$

While Phi_1 is known, Phi_{lh} and Phi_{rh} need to be solved. Phi_{lh} is the matrix that includes the force and torque values of left-hand and Phi_{rh} is the matrix that includes the force and torque values of right-hand.

$$Phi_{lh} = \begin{bmatrix} 0 & -\mathrm{mz_{lh}} & \mathrm{my_{lh}} & \mathrm{fx_{lh}} \\ \mathrm{mz_{lh}} & 0 & -\mathrm{mx_{lh}} & \mathrm{fy_{lh}} \\ -\mathrm{my_{lh}} & \mathrm{mx_{lh}} & 0 & \mathrm{fz_{lh}} \\ -\mathrm{fx_{lh}} & -\mathrm{fy_{lh}} & -\mathrm{fz_{lh}} & 0 \end{bmatrix} \tag{2}$$

:

$$Phi_{rh} = \begin{bmatrix} 0 & -\mathrm{mz_{rh}} & \mathrm{my_{rh}} & \mathrm{fx_{rh}} \\ \mathrm{mz_{rh}} & 0 & -\mathrm{mx_{rh}} & \mathrm{fy_{rh}} \\ -\mathrm{my_{rh}} & \mathrm{mx_{rh}} & 0 & \mathrm{fz_{rh}} \\ -\mathrm{fx_{rh}} & -\mathrm{fy_{rh}} & -\mathrm{fz_{rh}} & 0 \end{bmatrix} \tag{3}$$

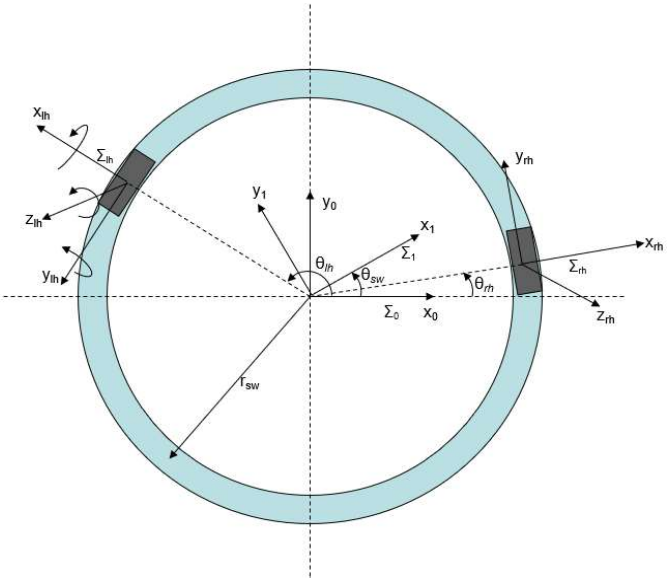


Figure 1b. Free-body diagram of steering wheel

The analytic analysis of the algorithms for solving Phi_{lh} and Phi_{rh} requires some assumptions. First of all, single hand driving condition is taken into account in this study. Therefore, in this case, it is supposed that only left hand is used while driving ($Phi_{rh} = 0$). Secondly, in this paper, the theory is configured based on long distance journeys that means that there will not be too often manoeuvres. As a result, according to these main assumptions, at the beginning, the relation between frame 1 and left-hand frame is needed to be defined. As seen from Figure 1b, left-hand frame is at a different angle with respect to frame 1. The rotation matrix [10] of frame 1 according to left-hand frame in Z axis by $\Delta\theta_{lh}$ is represented as:

$$R_{1lh} = \begin{bmatrix} \cos(\Delta\theta_{lh}) & -\sin(\Delta\theta_{lh}) & 0 & 0 \\ \sin(\Delta\theta_{lh}) & \cos(\Delta\theta_{lh}) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

$\Delta\theta_{lh}$ is the angle between frame 1 and left-hand:

$$\Delta\theta_{lh} = \theta_{\mathrm{lh}} - \theta_{\mathrm{sw}} \quad (5)$$

The translation matrix [9] of frame 1 to left-hand frame is defined as:

$$T_{1lh} = \begin{bmatrix} 1 & 0 & 0 & \cos(\Delta\theta_{lh})\, r_{\mathrm{sw}} \\ 0 & 1 & 0 & \sin(\Delta\theta_{lh})\, r_{\mathrm{sw}} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

As a result of Eq. (4) and Eq. (6), the transformation matrix [9] is calculated as:

$$H_{1lh} = \begin{bmatrix} \cos(\Delta\theta_{lh}) & -\sin(\Delta\theta_{lh}) & 0 & \cos(\Delta\theta_{lh})\, r_{\mathrm{sw}} \\ \sin(\Delta\theta_{lh}) & \cos(\Delta\theta_{lh}) & 0 & \sin(\Delta\theta_{lh})\, r_{\mathrm{sw}} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (7)$$

From the transformation law of Cartesian components of a tensor [10] the relation between Phi_1 and $Phi_{lh}$is defined as:

$$Phi_1 = H_{1lh} * Phi_{lh} * H_{1lh}' \quad (8)$$

In left sight of Eq. (8) six measured values from torque/force sensor are present($m_x, m_y, m_z, f_x, f_y, f_z$) as shown in Eq. (1). On the other hand, the solution of right sight of the equation is calculated and the results of the equations are:

$$P(1,:) = \begin{bmatrix} 0 \\ fy_{lh} * r_{sw} \\ fz_{lh} * r_{sw} * \cos(\Delta\theta_{lh}) - my_{lh} * \cos(\Delta\theta_{lh}) - mx_{lh} * \sin(\Delta\theta_{lh}) \\ fy_{lh} * sin(\Delta\theta_{lh}) - fx_{lh} * cos(\Delta\theta_{lh}) \end{bmatrix} \quad (9)$$

$$P(2,:) = \begin{bmatrix} fy_{lh} * r_{sw} \\ 0 \\ fz_{lh} * r_{sw} * \sin(\Delta\theta_{lh}) - my_{lh} * \sin(\Delta\theta_{lh}) + mx_{lh} * \cos(\Delta\theta_{lh}) \\ -fy_{lh} * cos(\Delta\theta_{lh}) - fx_{lh} * sin(\Delta\theta_{lh}) \end{bmatrix} \quad (10)$$

$$P(3,:) = \begin{bmatrix} -fz_{lh} * r_{sw} * cos(\Delta\theta_{lh}) + my_{lh} * cos(\Delta\theta_{lh}) + mx_{lh} * \sin(\Delta\theta_{lh}) \\ -fz_{lh} * r_{sw} * \sin(\Delta\theta_{lh}) + my_{lh} * sin(\Delta\theta_{lh}) - mx_{lh} * cos(\Delta\theta_{lh}) \\ 0 \\ -fz_{lh} \end{bmatrix} \quad (11)$$

$$P(4,:) = \begin{bmatrix} fx_{lh} * \cos(\Delta\theta_{lh}) - fy_{lh} * \sin(\Delta\theta_{lh}) \\ fy_{lh} * \cos(\Delta\theta_{lh}) + fx_{lh} * \sin(\Delta\theta_{lh}) \\ fz_{lh} \\ 0 \end{bmatrix} \quad (11)$$

At the right sight of the Eq. (8) there are six equations with seven unknowns($m_{xlh}, m_{ylh}, m_{zlh}, f_{xlh}, f_{ylh}, f_{zlh}, \Delta\theta_{lh}$). For making an analytic solution there is one more assumption needed about driver hand posture in this study. It is supposed that in normal driving conditions the driver is not applying torque at Z axis. Therefore, $m_{zlh} = 0$ and the new values of Phi_{lh} are shown below:

$$Phi_{lh} = \begin{bmatrix} 0 & 0 & \mathrm{my_{lh}} & \mathrm{fx_{lh}} \\ 0 & 0 & -\mathrm{mx_{lh}} & \mathrm{fy_{lh}} \\ -\mathrm{my_{lh}} & \mathrm{mx_{lh}} & 0 & \mathrm{fz_{lh}} \\ -\mathrm{fx_{lh}} & -\mathrm{fy_{lh}} & -\mathrm{fz_{lh}} & 0 \end{bmatrix} \quad (13)$$

As a result, according to this assumption the unknown values in Eq. (8) are solved as:

$$\mathrm{mz_{lh}} = 0 \quad (13)$$

$$fy_{\mathrm{lh}} = \frac{m_z}{r_{sw}} \quad (14)$$

$$fx_{\mathrm{lh}} = -\sqrt{fx^2 + fy^2 - {fy_{lh}}^2} \quad (15)$$

$$d = \frac{\begin{bmatrix} \mathrm{fx_lh} & -\mathrm{fy_lh} \\ \mathrm{fx_lh} & \mathrm{fy_lh} \end{bmatrix}}{\begin{bmatrix} fx \\ fy \end{bmatrix}} \quad (16)$$

$$\Delta\theta_{lh} = \mathrm{atan2(d(2), d(1))} \quad (17)$$

$$fz_{lh} = fz \quad (18)$$

$$A = \begin{bmatrix} \sin(\Delta\theta_{lh}) & cos(\Delta\theta_{lh}) \\ -\cos(\Delta\theta_{lh}) & sin(\Delta\theta_{lh}) \end{bmatrix} \quad (19)$$

$$b = \begin{bmatrix} my + r_{sw} * \cos(\Delta\theta_{lh}) * fz_{lh} \\ -mx + r_{sw} * \sin(\Delta\theta_{lh}) \end{bmatrix} \quad (20)$$

$$x = (A \backslash b)' \quad (21)$$
$$mx_{lh} = x(1)$$
$$my_{lh} = x(2)$$

While defining the values of forces and hand position it is possible to make a classification of driver inattention.

RESULTS AND DISCUSSION

From the results calculated in Equation (8) it is obviously seen that in single-hand driving conditions the $\Delta\theta_{lh}, fx_{\mathrm{lh}}, fy_{\mathrm{lh}}, fz_{\mathrm{lh}}, mx_{\mathrm{lh}}, my_{\mathrm{lh}}, mz_{\mathrm{lh}}$ left-hand values are defined. In the case of right-hand driving it is possible to calculate right-hand values with the same method. On the other hand, for solving the values with both hand driving conditions there must be some other assumptions. In Table (1) there are some assumptions made for force applied to X axis while driving.

θ_{sw}	Fx
$0° < \theta_{sw} < 90°$	Negative
$90° < \theta_{sw} < 180°$	Positive
$180° < \theta_{sw} < 270°$	Positive
$270° < \theta_{sw} < 360°$	Negative

The assumptions made in Table (1) are based on energy minimization theory of the human nature. Human beings always act in the way that consume less energy for the sake of survival needs. Therefore, while driving, the hand position and the applied forces depends on this theory and according to that, some other assumptions also can be made. Another assumption about driving conditions may be in the range of 225°-300° of θ_{sw}. At this range the force applied to Z axis is supposed to be negative and the applied moments are supposed to be zero. With the assumptions made above and the constrained optimization method the position and force values of both hands can be calculated. However, in this study, single-hand condition analytical solution is studied. The experimental system control and simulation is made in MATLAB / Simulink as shown in Fig. (2).

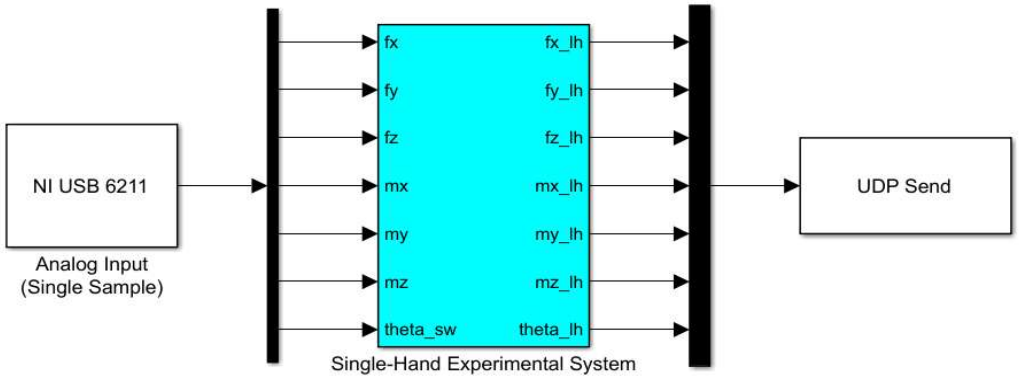


Figure 2. Simulink Model of Single Hand Experimental System

For making a classification about driver inattention real-time data collection from 50 different drivers at different driving conditions is needed. The "Unity 3D" game developer makes possible a real-time driving condition with vehicle simulation. An example of vehicle simulation is shown in Fig. 4. The steering angle that is changed by the driver is send on real-time to Unity with UDP, therefore the simulation becomes more realistic. For making accurate results, the driving conditions in Unity must be same as real conditions. In Unity it is possible to make various scenes like weather conditions, traffic, road bend, road width, traffic lights etc. Herewith, with different conditions various data will be collected.



Figure 3. Unity Vehicle Simulation Example[11]

CONCLUSION

In this paper while recognizing the driver's activity, real-time analysis of driver and steering wheel relation is discussed. There need to be some assumptions for calculating the torque/force values and the hand position with single-hand driving. In "Theory Section" of this paper, it is explained that in the normal driving conditions the torque value at Z axis is supposed to be zero. With that assumption, solving of Eq. (8) becomes possible. Therefore, left hand position and the torque/force values applied are calculated. With making a real driving condition at Unity 3D game developer it is possible to make a real-time data collection from different drivers. To sum up, the collected data according to hand position and force applied to steering-wheel will make possible for doing some classifications of driver inattention.

NOMENCLATURE

θ_{sw}	Steering wheel angle (°)
θ_{rh}	Angle between frame 0 and right-hand frame (°)
θ_{lh}	Angle between frame 0 and left-hand frame (°)
$\Delta\theta_{lh}$	Angle between frame 1 and left-hand frame (°)
r_{sw}	Steering wheel radius (m)
DAQ	Data Acquisition
Phi	Skew-symmetric matrix
R_{1lh}	Rotation matrix of frame 1 with respect to left-hand frame
T_{1lh}	Translation matrix of frame 1 with respect to left-hand frame
H_{1lh}	Transformation matrix of frame 1 with respect to left-hand frame
UDP	User Datagram Protocol
NI	National Instruments
USB	Universal Serial Bus

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