Proceedings of the 2009 IEEE International Conference on Systems, Man, and Cybernetics
San Antonio, TX, USA - October 2009

Development of a Sensor System for Grasp Behavior on a Steering Wheel

Takashi IMAMURA*, Zhong ZHANG*, Tetsuo MIYAKE* and MD Rizal bin OTHMAN*
Department of Production Systems Engineering
Toyohashi University of Technology
1-1, Hibarigaoka, Tempaku, Toyohashi, Aichi, JAPAN
Email: {ima,zhang,miyake,rizal}@is.pse.tut.ac.jp

***Abstract*—The prevention of car accidents is one of the main issues in any car-oriented society. A method for this kind of prevention system is the estimation of the driver's conditions based on human sensing. This research's aim is the development of a measurement system for human behavior by using contact sensing on a steering wheel. In this paper, a sensing system using an array of small pressure sensors is proposed, and a design method for the sensor part on the steering wheel based on a fundamental analysis of the driver's operation of the steering wheel and its validity are discussed. Finally, characteristics of the proposed sensor system are evaluated through implementation on a real steering wheel device.**

***Index Terms*—Driver sensing, Safe assisntance system, Steering wheel**

I. Introduction

In recent years, the number of deaths due to car accidents has decreased according to the development and the implementation of crash safety systems for vehicles and drivers, for example, the air bag system, energy-absorbing chassis and braking-assist systems. However, the number of car accidents has still remained high over the last 20 years. According to a statistical survey by ITARDA (Institute for Traffic Accident Research and Data Analysis, Japan) and the White book of Traffic Safety, Cabinet office, Government of Japan, more than 6,000 accidents occur every year. Their analysis results show that in more than 70[%] of cases, the reasons for accidents are cognitive and judgemental errors of the car driver. These matters are one of the big problems in our daily life, and therefore a number of researchers and companies are attempting to develop new technology which can minimize these kinds of accidents.

One solution for these kinds of serious accidents is an estimation system for the driver's state based on human sensing. Methodologies of human sensing have been proposed by using camera images, vocal audio signals, biological signals and so on. They are classified into contact and non-contact methods by their type of sensing of the driver. Non-contact methods, for example image acquisition by using CCD cameras, and surface temperature by using near infra-red, are stress-free methods compared with contact methods for the subject driver, but they suffer from sensing noises and uncertainty in the relationship between the sensing data and the real situation. On the other hand, contact methods restrict the subject's behavior when necessary and place sensor probes and their cables on the human body's surface. However, contact methods have the possibility to realize more precise sensing of human behavior or biological information.

Previously, the authors have been researching non-contact sensing for eye-gaze or facial expression by using an image processing technique as shown in Figure 1. Their results succeeded in acquiring a human's information by a single camera with simple equipment, but it was difficult to clarify the relation with biological information.

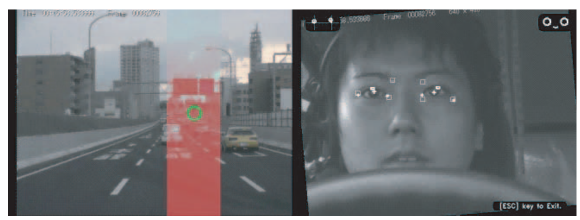

Fig. 1. Example of non-contact driver measurement in previous research

Several researchers also studied about the driver's handling behavior. EKSIOGLU[1] et al investigated the relationship between driver's gender, driving speed and road condition and the characteristics of grip force. He conducted the experiments with 13 subject driver, and concluded the grasping force differences for in gender without influences from driving environments by the analysis results. However, the measurement point for grasping force was fixed in one point on the steering wheel. On the other hand, KODAIRA[2] et al investigated the grasping feeling of driver in the experiment for meandering driving with lateral direction force measurement. And the importance for grasping feeling on the steering wheel in the ealuation for driver's satisfaction had cleared. TANAKA[3] et al also analysis the steering wheel operation by estimation for human hand impedance properties using mechanical linkage model. From their result, the grasping point on steering wheel have significance to reduce the driver's operational load and a driver will change the upper and lower position on steering wheel according to the driving environment in order to improve their operational force.

Recently, several micro-chip sensors which can detect the pH of a person's sweat or the blood flow through a person's skin have been developed. They have the possibility to achieve

978-1-4244-2794-9/09/$25.00 ©2009 IEEE

more precise and more stress-free human sensing if the sensor arrangement is designed correctly for stable detection. In a vehicle driving situation, there are some contact sensing methodologies using the driver's necessary behavior for vehicle driving. Steering wheel operation is one such important behavior for vehicle driving which involves grasping the steering wheel. From this viewpoint, we have investigated the characteristics of steering wheel operation with several subject drivers. Based on the knowledge gained through experiments, a multiple-pressure sensor system implemented on the steering wheel is proposed in this research.

In this research, a sensor system for grasp acquisition using micro pressure sensors inside the steering wheel is proposed. Important problems in this system are the arrangement design of the multiple sensors and the selection method for their information. For these problems, the designing process for the sensor arrangement based on grasping behavior collected in fundamental experiments has been discussed. In particular, several characteristic points on the steering wheel for contact with the driver's hands in their operation were specified by the experimental results. These points together with features of the shape of the steering wheel are applied to the design for sensor arrangement. Finally, the a sensor system has been implemented in a real steering wheel and basic experiments have been conducted in order to evaluate the characteristics of the sensors and to examine the processing method for sensor information.

II. Proposed sensor system and its design

In this section, a sensor system which can detect the grasping behavior of a driver on the steering wheel is proposed. An overview of the construction of the system and design strategies is also described.

A. Purpose of the sensor system

Grasping or handling behavior of a driver on the steering wheel is one of the characteristics of driving a car. Generally, it is said that a human's behavior of their hands includes several symbolic gestures related to their emotions or situations. Moreover, when people drive a car, they usually operate the steering wheel with their bare hands. This makes it possible to apply several biological sensors. On the other hand, sensors which need contact with human skin usually suffer from sensor noise if they are highly sensitive for biological sensing. Therefore, sensor selection or sensing strategy becomes more important when a multiple sensor array is used.

From this viewpoint, the proposed sensor system is designed to detect the grasp position by pressure to determine the suitable position of human skin for biological sensing. Figure 2 shows the shape of the sensor probe used in this system. SENSOR PRODUCT INC. provides several kinds or shapes of micro force sensors, and for the proposed system a sensor which is 5[mm] square in size was chosen to be installed inside the steering wheel. Each sensor acquires the pressure force on each sensor probe and is collected by a single unit, which then transmits all of the pressure data to a PC via USB2.0 every 50[msecs].

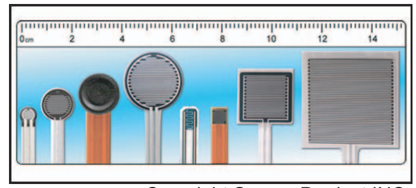

Fig. 2. Photograph of sensor probe shapes provided by SENSOR PRODUCT INC.

B. Overview of the sensor system

The proposed sensor system consists of a steering wheel and 28 pressure sensors described in the previous subsection as shown in Figure 3.

The steering wheel used in this sensor system was manufactured by TOYODA GOSEI Inc., and is the preliminary part of the driving simulator DS-6000 manufactured by MITSUBISHI Precision Inc. Therefore it has compatibility with a driving simulator system, and testing or evaluation for this sensor system can be conducted in an environment similar to a real driving environment.

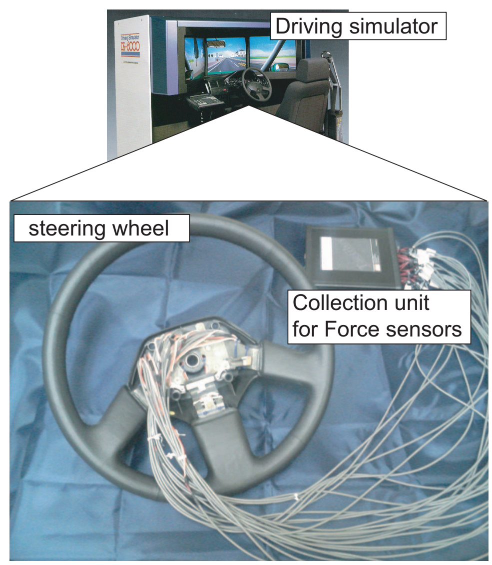

Fig. 3. Overview of the proposed sensor system with steering wheel

Each pressure sensor inside this system only has sensitivity in one direction. In order to acquire several directions of handling behavior on the steering wheel with these pressure sensors, examination of the sensor arrangement is necessary.

C. Definition of basic arrangement of Sensor probe

The tip of the sensor probe consists of square shaped conductive rubber, and it has 1[mm] thickness. The pressure force perpendicular to the plane of rubber is only measured by this sensor.

On the other hand, most of the steering wheel consists of a cylindrical shape which is deformed into a ring shape, and the cross-section shape of the part is circular. According to this circularity, forces in any direction are possible to occur by the driver's grasp. The whole steering wheel is circular with spokes and it can be considered disk-shaped. Almost all of the operational force will occur in the direction perpendicular to the disk plane, because the driver will operate the steering wheel while facing it. Moreover, the grasp force from the driver's finger will apply force radially. Figure 4 shows the classification of the grasp force described above. In particular, a point on the upper or lower part of the steering wheel in one rotational position also has radial force from the outside or inside of its ring shape and is shown as "force (c)". The facing forces on the disk shape are shown as "force (a)" and "force (b)" respectively.

Considering this kind of classification, the basic arrangement of a point to set a sensor probe is determined.

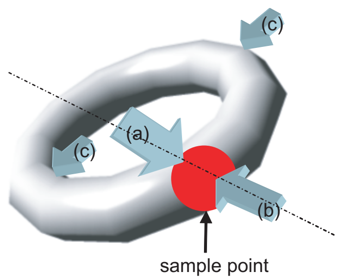

Fig. 4. Classification of force direction on steering wheel

D. Selection of point to arrangement of Sensor probe

The basic sensor arrangement on the circular shape of the steering wheel has been discussed in the previous section. However, the steering wheel also has a spoke section which connects its circular shape to the steering shaft. This spoke section also has several variations as shown in Figure 5. For example, the steering wheel used in this research is shown in Figure 5 (c).

By considering the arrangement of the sensor probe on the spoke part, the shape of spoke shown in Figure 5(a) was selected as the typical shape. In this case, the point connecting the circular shape to the spoke is most contacted part of the handling behavior. Normally, almost all drivers grasp the part of the ring of the steering wheel as shown in Figure 6(a). In some cases, drivers also put on their hands on the upper part of the spoke-circle connection as shown in Figure 6(b), or grasp the circular part between the spokes as shown in Figure 6(c). From the results of interviews of these subject drivers, the reasons given for the hand placement included giving their hands or arms a rest, and that is was the most suitable configuration of their hands and arms.

As the investigation results for 11 subject drivers by using image acquisition for their grasping behavior and by interviews, important points about pressure force sensing near the connection point between the spokes and circle have become clear. In addition, the 12 points around the circle are also selected as the main grasping points. Finally, optimization for the arrangement points has been conducted which considers the conflicts between the sensor probes in the actual arrangement and the sensing area for one sensor probe on the steering wheel.

Candidate sensor arrangement points were decided, and the steering wheel with the sensor system was manufactured based on the points as shown in Figure 3.

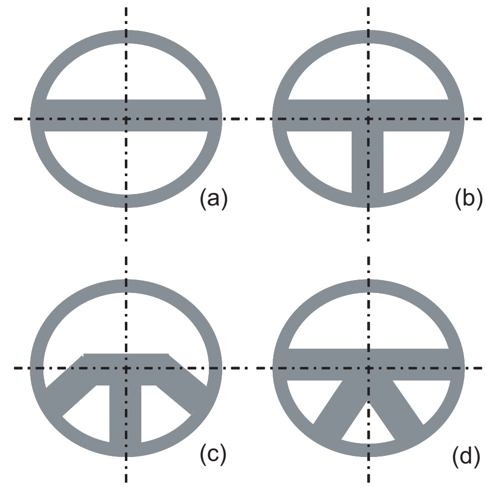

Fig. 5. Sample steering wheel spoke shapes

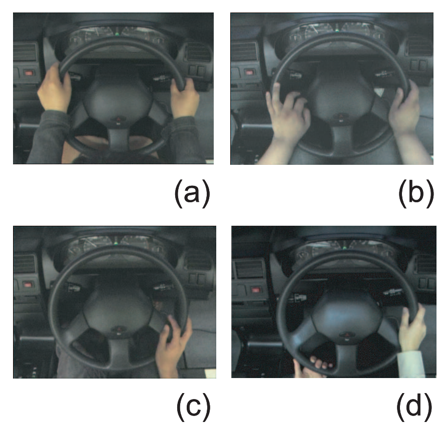

Fig. 6. Examples of grasping styles of the steering wheel and spoke

III. Evaluation of the sensor system

The implementation of the sensors to the steering wheel was conducted based on the considerations above. In this section, an evaluation of the sensor system through fundamental experiments using the sensor system is performed.

Especially, the sensor system which is installed in real vehicle system, characteristics of endurance, stability for long time measurementation. Therefore, driving experiment on driving simulator which is installed the trial product of proposed sensor system was conducted. Finally, measurement data was evaluated from the viewpoint of required characteristics.

A. Mechanical problem of the system

A serious problem of the proposed system is the wiring for the sensor cables. In this system there are 28 sensors inside the steering wheel, and the sensor cables occupy the wiring space where the tip of the sensor probe is small. The most inconvenient aspect of the steering wheel is that the cables constrain its movable range.

Recently, the implementation techniques for air-bag control or security parts for the steering wheel have already been developed to avoid these kinds of problems. As future work, a wired or wireless connection with each sensor is needed.

B. Sensor characteristics

The sensor values were already calibrated before installation inside the steering wheel. However, in the manufacturing process, the outside leather has to be tightened to avoid slackness between the core of steering wheel and leather, and this tightening applies a constant pressure force on the sensor probe as a bias value.

In this system, detection of the changes of a driver's grasping force is main importance, and consequently the sensor value can be used as a relative value even though it contains a bias value. The evaluation results as show in next subsection that the sensor can detected grasping behavior in which the driver put his hand on a point, then moved his hand to another point and then back to first point. Furthermore the experiments confirm that the system has enough sensitivity in force detection and time resolution.

C. Trial implementation and sensor system charactoristics in driving environment

The driving experiments using driving simulator shown in Figure 3 with 1 subject driver have conducted. In this experiment, trial product of proposed sensor system have installed in the driving simulator system while it have an problem for their wiring. Then, the driving environment in express way has applied as test course environment with another cars running at 100[km/h]. The driving course has a circular shape and one exit, and it take 15[min] to cruise around the course. In this experiment, subject driver had driving a car for 15[min].

Figure 7 shows exprimental result of force measurement and driver's bahavior on the steering wheel. Sensor system has 28 point force sensors inside the steering wheel. Among these sensors, we focused 8 points which are used in ordinary grasping style of driver, A to D and A' to D'. Sensors A to D measure putting force on the surface of steering wheel, and Sensors A' to D' measure grasping force on radial direction of steering wheel.

On the force plot in this figure, there are pulse shape force on Sensor A and A' from 5 to 15[sec]. They caused by calibration motion of driver as shown in upper photograph. And Sensor D has rapidly changed force at 50[sec] which was coused by rotational operation for turn right as shown in middle photograph.

Several sensor data could be measured in 15[min] experiment, and it is confirmed that the proposed system work well in enough time to driving, and the measurement data and driver's operation have good correlation and sensitivity to analysis their dynamics.

IV. Conclusion

In this paper, a contact sensing system for the driver's grasping behavior has been proposed. The system was constructed by using small pressure sensors, and the methodology for optimizing the sensor arrangement based on the investigation results of a driver's grasp style has also been proposed. Finally, using a manufactured system on the driving simulator, the effectiveness of the proposed system for the grasping behavior acquisition has been confirmed through fundamental experiments. However, several weakness of the proposed system also exist, and therefore the problems, especially the mechanical wiring problem must be corrected as soon as possible. After this, as further work, more actual experimentation on the driving simulator will need to be conducted in order to clarify any problems in practice, as will acquiring the driver's behavior through driving experiments.

Acknowledgment

This research was partlially supported by the Activation program for research and education, Toyohashi University of Technology, the Global COE Program "Frontiers of Intelligent Sensing" and KAKENHI Grant-in-Aid for Young Scientists (B), 21760195, 2009 from Ministry of Education, Culture, Sports, Science and Technology(MEXT), Japan. The authors would like to thank the related staff in T.U.T.

References

[1] M. EKSIOGLU and K. KIZILASLAN, *Steering-wheel grip force characteristics of drivers as a function of gender, speed, and road condition*, International journal of industrial ergonomics, Vol.38, No.3-4, Page.354-361, 2008.

[2] T. KODAIRA, M. OOKI, H. SAKAI, E. KATSUYAMA, Y. MURAGISHI, K. FUKUI and E. ONO, *Vehicle Transient Response Based on Human Sensitivity*, Society of Automotive Engineers technical paper series, SAE-2008-01-0597, 7p., 2008.

[3] Y. TANAKA, R. KANDA, T. TSUJI, Y. TAKEDA, N. YAMADA, K. FUKUBA and I. MASAMORI, *Analysis of Human Hand Impedance Properties during the Steering Operation(in JAPANESE*,Transactions of the Society of Instrument and Control Engineers, Vol.42, No.12, Page.1353-1359, 2006.

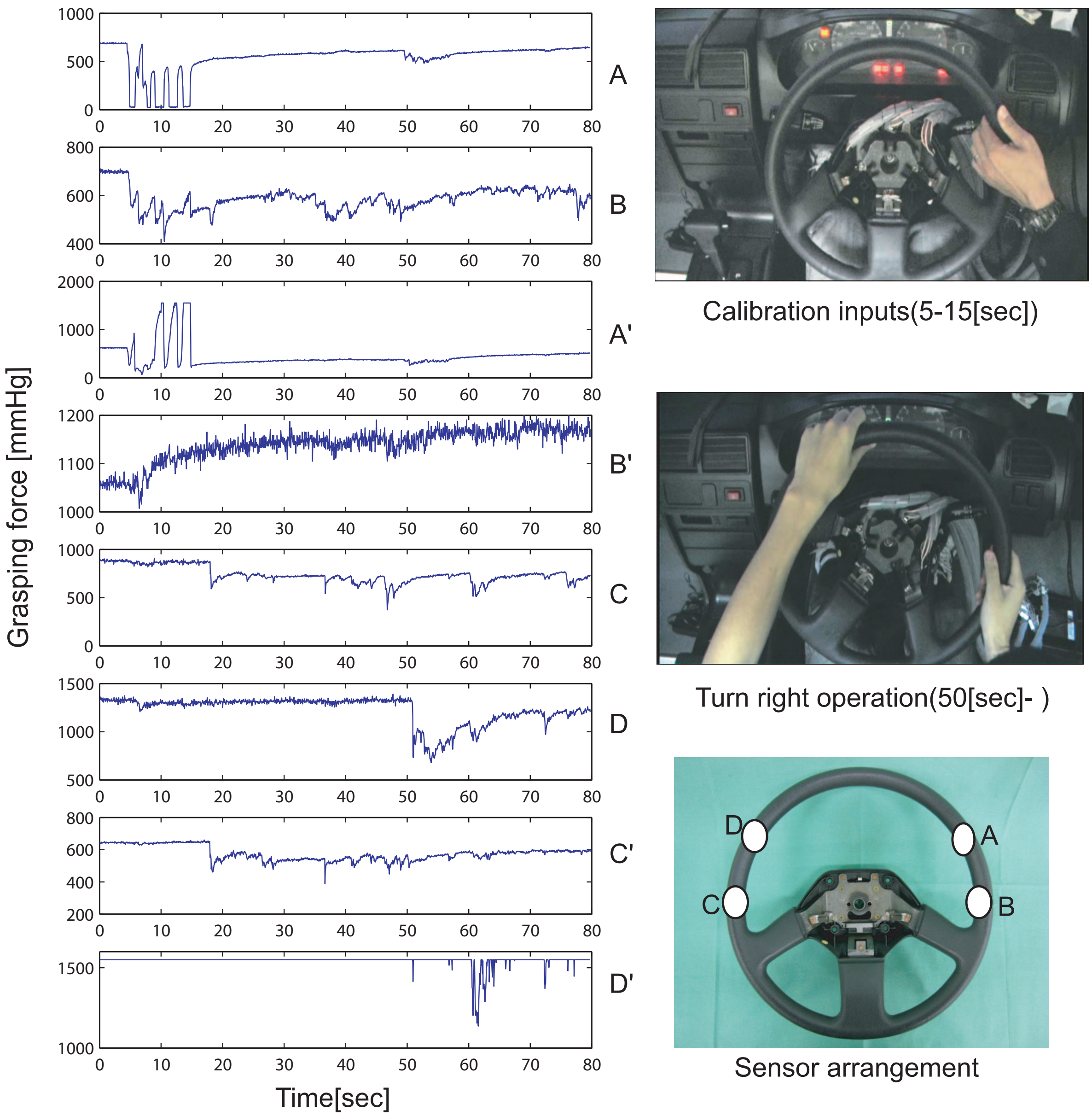

Fig. 7. Sample grasping data acquired by the proposed sensor system on DS-6000