Real time inference of driver's intent via analyses of pressure distribution on the seat

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Abstract: This paper discusses effectiveness of utilizing pressure distribution on driving seat for developing proactive safety systems. In particular, this paper proposes an algorithm for detection of body movement due to an unnecessary action and identification of an action based on analysis of the load centre position of seat back. The result shows that detection of body movement itself is successful. However, accuracy of the action identification may not be adequate. Further studies would be necessary for improving the hit rate of identifying an action.

Keywords: ITS, Preventive safety, Tactile sensor, Driver monitoring

1. Introduction

In Japan, recent development of passive or reactive safety technologies contributed to reduce the number of deaths due to road traffic accidents. However, the number of accidents has not been reduced adequately. It is necessary for us to establish "proactive" safety technologies.

Among several types of road traffic accidents, one of the most important types is vehicle-to-vehicle rear-end collision. In order to reduce the risk of rear-end collision, what must be done? Several driving assistance systems have already been put into market, such as Adaptive Cruise Control (ACC) systems or Pre-Crash Safety (PCS) systems. However, neither ACC systems nor PCS systems work for "preventing" an imminent accident. An ACC system is for keeping appropriate headway distance when the traffic situation is peaceful. On the other hand, a PCS system hits the brake hard for reducing "damage" only when a rear-end collision cannot be avoided. Note here that there is no system for "preventing" an imminent accident. This is because car manufactures and government people are anxious about driver's too much reliance on such a "preventing" system.

So what can we do? One possible way is to develop a system for managing driver's commitment to driving. If a driving assistance system were successful in managing driver's commitment (i.e., when a system detects driver inattentiveness, the system provides an appropriate support), the probability of occurrence of accidents would be reduced. Moreover, a "preventing" system might be allowed to work when a non-complacent driver fails to hit the brake by some reason. Thus, it is necessary to establish methods for understanding driver physiological or psychological state.

In order to establish practically effective methods for driver monitoring in the real world, the number of sensors should be small. Also, each sensor should not be expensive. This paper discusses about the management of driver commitment to driving. We propose to apply a pressure distribution sensor on driving seat to the management. In section 2, the framework is shown. In section 3, we discuss why we focus on the pressure distribution on driving seat. In section 4, an algorithm for detecting driver distraction is proposed. In section 5, the proposed algorithm is tested by conducting an experiment. In section 6, we conclude this paper.

2. Framework

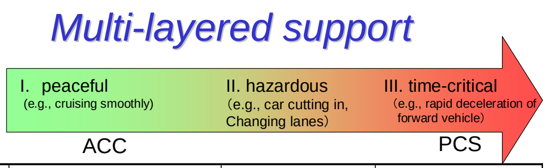
2.1 Multi-layered driving support

In this paper, "multi-layered" has several meanings. For example, we consider the problem of driver monitoring for driving assistance in two aspects, i.e., long term and short term.

In the sense of the long term, it is necessary to develop a method for detecting driver fatigue and drowsiness due to long time drive. When a system detects the driver fatigue or drowsiness, the most effective countermeasure is to make the driver rest at least for a while. It is true that intervention of a driving assistance system into control when a driver is severely fatigued or sleepy might work well for attaining safety in a particular situation. However, development of such a system should be carefully done.

On the other hand, more detailed consideration is necessary for the short term driver monitoring and driving assistance. Multi-layered structure can also be seen here as shown in Figure 1. This structure is based on the idea in [2].

When a time-critical event (such as rapid deceleration of a forward vehicle) occurs, a driver may delay in initiating safety control actions by some reason. At this phase, it is necessary to monitor driver behavior and to provide appropriate assistance to the driver if necessary. The major measure of driver's attentiveness may be based on manual control inputs. When a system detects that a crash is imminent but there is no driver action for preventing accident, it might be necessary for the system to intervene into control for attaining safety.



(1) Estimation of driver state	(a) Cognitive distraction (b) Biomechanical distraction	(d) failure in preparation (e) Inappropriate intention	(e) failure or delay in safety control actions
(2) enhanceme nt of SA	Support awareness of own state, task re-allocation	Support level 1 SA on traffic	Support levels 2,3 SA on traffic, or reminding necessary actions
(3) System intervention	System engaged, Get ready	Envelope protection	system-initiated safety control in emergency

Figure 1: Multi-layered support (short term)

When the traffic condition is hazardous but not requiring driver's immediate response, driver's inattention may result in lack of "preparation." An example is given in Figure 2. Suppose the host vehicle (H) is following a forward vehicle (F) and another vehicle (A) is cutting in front of car F. In this case, the car F may decelerate rapidly in the near future for preventing a collision to car A. In order to maintain safety of the host vehicle, the host driver may have to "prepare" to hit the brake. It can be assumed that this kind of "preparation" is required to professional drivers. If the system detects that such proactive actions are omitted, the system judges that the driver's attention to driving is not adequate. Since such "preparation" may not be detected on the basis of manual control inputs to the vehicle, driver-monitoring systems should be able to recognize driver's "motion". Another example in this phase is driver's checking of the side mirror when he or she is trying to change lanes.

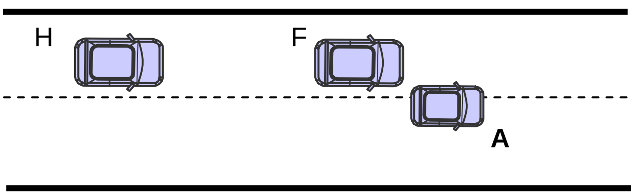


Figure 2: An example of situations in which a driver in a host vehicle (H) should "prepare" to implement safety control actions (Vehicle A is cutting in just front of vehicle F)

Assume the traffic condition is very peaceful, is there no problem? The answer might be "no." it is still necessary to detect driver's inattentiveness to driving in order to achieve "proactive" safety. Even when a driver is neither fatigued nor drowsy, the driver can be in inattentive psychological state by doing non-driving related activity, such as "thinking" or "talking" on a cellular phone. This type of inattention is sometimes called "distraction." Ranny et al. [10] distinguished four categories of distractions: "visual", "auditory", "biomechanical", and "cognitive". "Visual distraction" stands for "looking aside." When a driver is performing a cognitive task which does not require driver's motion (e.g., thinking about something serious issue), it is called that the driver is "cognitively distracted". Since we can assume that driver's mental workload may increase when the driver is performing a cognitive subtask during diving, at least some part of cognitive distraction can be detected with measurement technique of mental workload. "Auditory distraction" refers to paying driver's attention to hearing something (e.g., radio or music) too much other than driving. Biomechanical distraction stands for situation in which a driver is performing a task which requires driver's motion, e.g., looking at something irrelevant to driving, or taking something to eat/drink. As shown the above, method for detection of driver distraction should be different from category to category.

2.2 Multiple use of pressure distribution on driving seat

In this paper, we propose using pressure distribution data on driving seat for the multi-layered driving support. It is true that sensor fusion approach is effective for developing highly accurate driver monitoring systems (e.g., see, [4]). However, in order to develop a cost effective system, a system that requires multiple expensive sensors might not be practical, especially for small cars. On the other hand, a pressure sensor on driving seat may be effective in a sense that the sensor can be used for multiple purposes. Figure 3 illustrates a strategy for applying pressure distribution data to driving assistance.

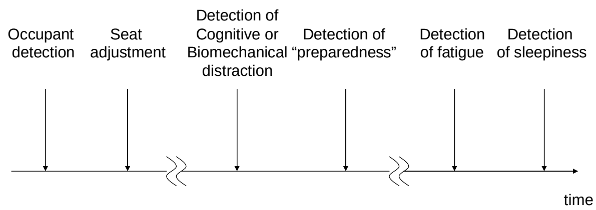


Figure 3: Strategy for applying pressure distribution data to driving assistance

<u>Occupant detection</u>: Several types of tactile pressure distribution sensors have been already developed for occupant detection (e.g., see, [6, 8]). These sensors can be also used for adjusting seat position for better driving posture and for controlling the explosion of an

airbag according to the physical figure of a driver or a passenger.

Fatigue: Furugori, et al. [1] suggest that driver fatigue can be detected by analyzing the load center position of a driver on the seat cushion. According to [1], the load centre position (LCP) can be calculated with 6-8 strain gages embedded on a seat cushion. Therefore, the cost of implementing a load centre position measurement system may be relatively low if we can focus on developing a system for detecting driver fatigue.

Drowsiness: Maeda, et al. [9] developed a driving seat which has an air-pressure sensor from which the driver pulse-wave of the blood flow can be extracted. Kaneko, et al. [7] show that the pulse-wave can be used to predict driver dozing.

Distraction: Pressure distribution data is useful for not only detecting driver fatigue and drowsiness but also detecting distraction. Itoh, et al. [3] showed that driver body movement could be reduced when a driver's mental workload was high due to doing cognitive activity.

What else about distraction? Even though it might be difficult to detect visual or auditory distraction with pressure distribution sensors, it might be able to develop a technology for detection of biomechanical distraction. However, there is less researches of detection of biomechanical distraction by analyzing pressure distribution data on driving seat.

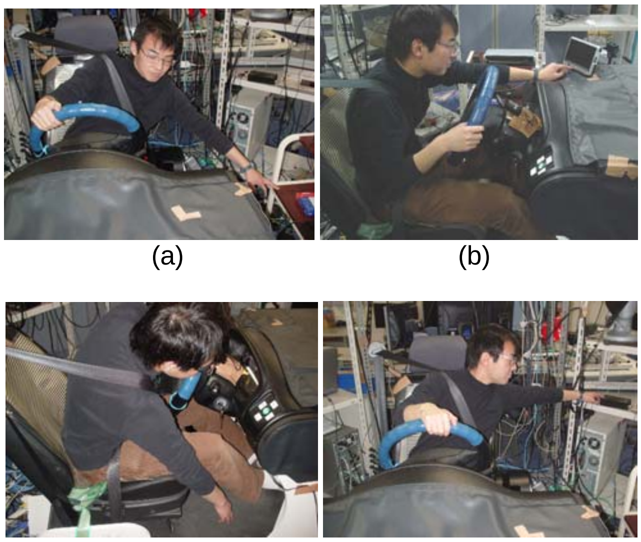
"Preparedness" in risky situation: The technology for detecting biomechanical distraction could be also used to evaluate driver's "preparedness" for hitting the brake when the risk in traffic situation is increasing as shown in Fig. 2.

The method of detecting biomechanical distraction or the "preparedness" is vital because it can be more acceptable than methods using video image, because some drivers may dislike to be videotaped even in a car. Thus, the aim of this study is to develop methods to detect driver biomechanical distraction and/or "preparedness" for hitting the brake. In this paper, we focus on the detection of driver biomechanical distraction.

3. Problem setting and pressure distribution measurement system

In our study, the following five categories are distinguished.

- C: to correct the driving posture
- P: to take something on the cushion of the passenger seat, and to put it back (Figure 4(a))
- N: to operate a navigation system (Fig. 4(b))
- F: to pick up something under the participant's foot (Fig. 4(c))
- B: to take something on a backseat (Fig. 4(d))



(a) (b) (c) (d)

Figure 4: Simulated movements as unnecessary actions during driving

These categories were extracted from observations of real professional truck drivers in the real world [5].

In this study, we utilize a pair of sheet pressure sensors which can measure pressure distributions of both the back and the seat cushion (Figure 5). Potentially, the sheet sensors are simple and strong enough to be embedded on a driving seat.

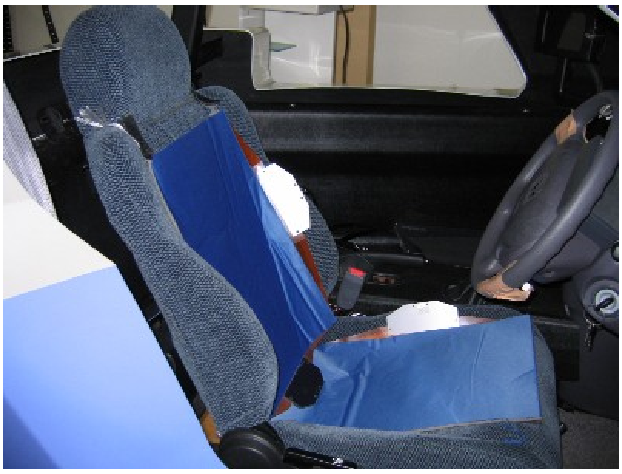
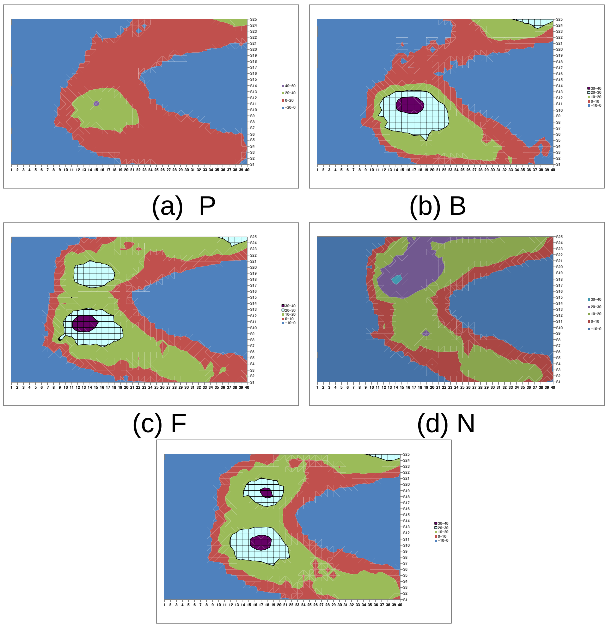


Figure 5: Sensor sheets

With the sensors, pressure distribution is measured consecutively in time. The sampling interval is 0.5 sec. At each sampling time, each sensor sheet measures the values of the load from every sensing unit. One sheet sensors has 44 (row) x 48 (column) sensing units. Figure 6 depicts examples of pressure distribution for the four action categories except C and for no action.



(a) P (b) B

(c) F (d) N

No action

Figure 6: Examples of pressure distributions

4. Method of detecting driver body movement and identifying an action based on load centre position of the back

It might be possible that we have to reduce the cost of the measurement system we develop (some functions should be given up in this case). According to Furugori, et al. [1], the load centre position can be calculated by using 6 to 8 strain gages for each of the back and the seat cushion. In this sense, it is meaningful if we can develop a method of detecting driver biomechanical distraction on the basis of LCP.

4.1 Preliminary analysis

Before developing an algorithm for detecting driver action, we collected the data. Five undergraduate students, called #1 to #5, participated in the data collection. Each participant had a valid driver's license.

We observed the time series of the LCP-B. Let (R_i, C_i) be the LCP-B at time point *i*. In this paper, the LCP on the back (denoted LCP-B) is utilized for driver's action analyses.

The coordinate systems are as shown in Figure 7.

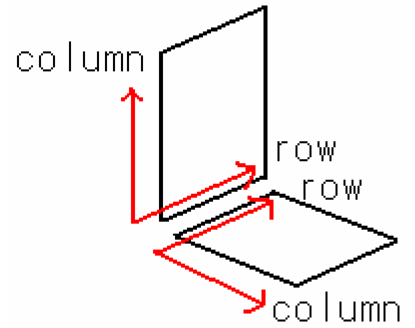
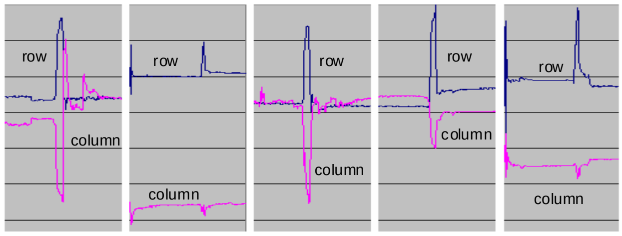


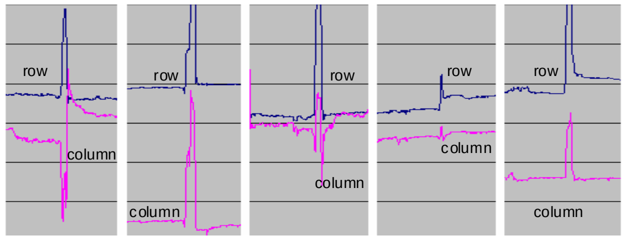
Figure 7: Axes of the sheet sensors

Figures 8-12 show examples of the time series of the LCP-Bs.



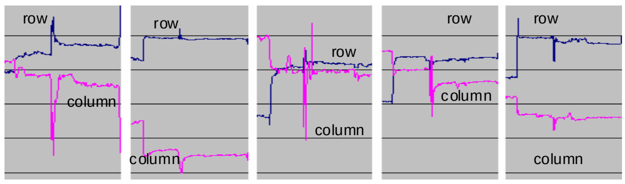
#1 #2 #3 #4 #5

Figure 8 Examples of movement of the load center position of the back (Reaching to the passenger seat)



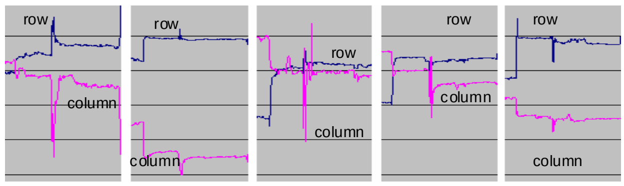
#1 #2 #3 #4 #5

Figure 9: Examples of movement of the load center position of the back (Reaching to the back seat)



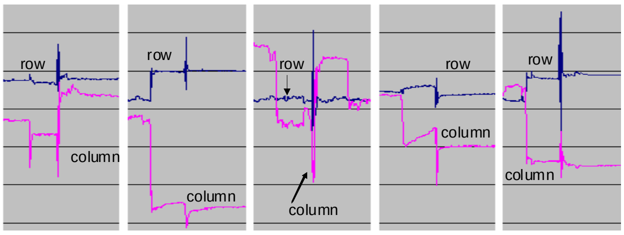
#1 #2 #3 #4 #5

Figure 10: Examples of movement of the load center position of the back (Reaching to the floor)



#1 #2 #3 #4 #5

Figure 11: Examples of movement of the load center position of the back (Operating the navigation system)



#1 #2 #3 #4 #5

Figure 12: Examples of movement of the load center position of the back (Correcting driving posture)

4.2 Method of detecting “movement” and identifying action

According to the preliminary analysis, we have developed an algorithm to detect driver unnecessary action and to identify one. We assume that both R_i, and C_i are normally distributed when a driver focuses his or her attention only to driving, and that estimated values of the population means and variances are obtained beforehand by sampling the LCP-Bs under normal driving condition. The unbiased estimates of the population variances of R_i and C_i are denoted as Vr^2 and Vc^2, respectively. Let Sr_i^2 and Sc_i^2 be the unbiased sample variances of R_i and C_i, respectively, calculated from the data in the latest 10 time points (i.e., approximately 5 sec.).

The procedure to detect movement of driver body and to identify an action involves the following steps:

Step 1: Determine whether a driver is making a movement of something or not. The driver is regarded as making “a movement” when at least one out of the two variances Sr_i^2 and Sc_i^2 is significantly greater than the reference value given in advance. Concretely speaking, tests about a single population variance are done for both Sr_i^2 and Sc_i^2 with the statistics:

$$\chi_r^2 = (10-1)\ Sr_i^2 / Vr^2, \quad \chi_c^2 = (10-1)\ Sc_i^2 / Vc^2,$$

where each of the above follows a chi-square distribution with 10 degree of freedom. The rejection region is set on the right. The significant level is set at 0.01.

Step 2: If a movement is detected in Step 1, then go to Step 3. Otherwise, do Step 1 at the next time point.

Step 3: Narrow the possibilities down to small number of candidates. This is done on the basis of the deviation direction of the LCP (see, Figure 13). As shown in Figure 13, (P) and (N) are not distinguished to each other in this method. Since some noise is added to each of R_i and C_i, identification of the deviation direction is not straightforward. In this study, the threshold of detecting the "deviation" of the LCP-B was set at 0.9 inches for both the row and the column axes.

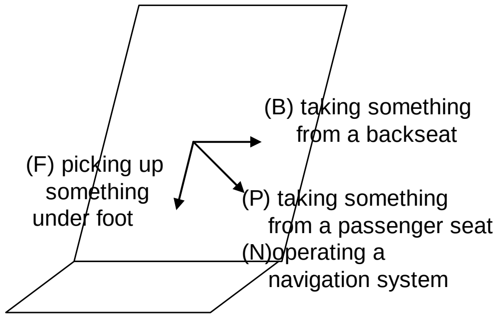


Figure 13: Deviation direction of the LCP-B (driver’s seat is located on the right-hand side)

If the deviation of the LCP-B was observed in the all directions (back and forth, and right and left) in a very short time, then we regard that the driver had corrected his or her posture.

5. Experiment

5.1 Method

Purpose: We investigate whether unnecessary actions can be detected and identified via analysis of LCP-B using the proposed detection algorithm.

Participants: The five undergraduate students, #1 to #5, participated in this experiment.

Tasks and Design: Participants were asked to drive safely in a fixed-based driving simulator. The traffic was configured as peaceful. The participants were also required to perform the unnecessary actions during driving. The numbers of performing actions are shown below:

- C: 13 times
- P: 22 times
- N: 9 times
- F: 7 times
- B: 10 times

Procedure: Data collection for each participant was done as the following procedure.

(1) Experimenter explained to a participant the purpose of this data collection.

(2) The participant received practices of performing the actions.

(3) Practice drives were given in order for the participant to familiarize driving in the simulator. The practices were finished when the participant felt that he or she had got enough skill for performing the tasks.

(4) The participant received ten runs for data collection. Time length of each run was 16 minutes. The number of movements in a run differed from run to run depending on the sequence of the movements. The minimum was seven and the maximum was 10.

Measures: From the raw data, the load centre positions were calculated. For each run, the data of the first 30 seconds, in which a participant drove smoothly, was used to calculate the estimated value of the population variances of the LCP-B. In this sense, the detection algorithm is driver-dependent and situation-dependent.

Evaluation system: The evaluation of the algorithm is done by testing a program that runs according to the proposed algorithm. The program was written in C language. The size of the execution file is approximately 69 KB. In this experiment, the evaluation itself was done in an off-line manner. However, online evaluation is feasible. If more than one action were identified after participants performing of an action, we recorded that the multiple actions as "candidates."

5.2 Results

Table 1 shows the result of detection of driver's making a movement (Step 1). Detection of a movement when a driver is really making a movement was 100% for every driver. On the other hand, the numbers of false detection over 160 min (10 times 16 min run) were from 6 to 24 as shown in Table 1. Even though we need to reduce the number of false detection, driver's making a movement can be detected effectively. Note here that after this experiment, we did another test in which the experimental set up was almost the same except for driving simulator. In the latter experiment, we utilized a motion-based driving simulator. The result showed that detection of movement was 93.5 % in total. Thus, these results suggest that detection of movement is successful even in a real car running in the real world.

Table 1: Detection of making a movement

Participant	A	B	C	D	E
Hit rate	100%	100%	100%	100%	100%
# of false detection	16	24	6	11	6

Figure 14 illustrates how much each type of movement was detected in a sense that the particular type is included in a candidate set which had been narrowed as a result of Step 3 of the detection algorithm. As shown in this figure, picking up candidate was successful in general. However, the detection rate on "picking up something from a backseat" was not high enough.

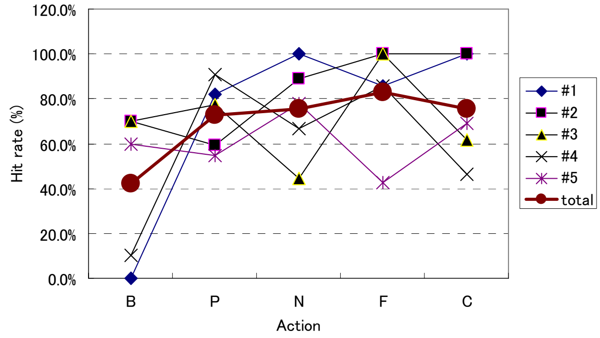


Figure 14: Rates of hit in a sense that the particular movement is included in candidate set

Figure 15 shows the rate of the proper hit, i.e., only one action was identified correctly.

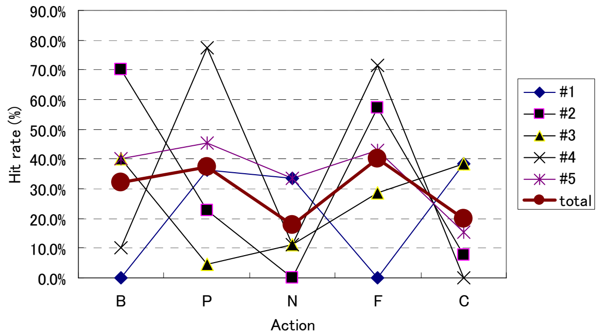


Figure 15: The proper hit rate

6. Discussion and concluding remarks

This paper discussed effectiveness of utilizing pressure distribution on driving seat for developing proactive safety systems. Potentially, the pressure distribution can be useful for multiple purposes.

In particular, this paper showed an algorithm for detection of unnecessary body movement and identification of an action based on analysis of the load centre position of seat back. The result showed that detection of body movement itself was successful. If we would like to develop a system which detects "change" of driving posture for preventing increase of potential risk, the method shown in this paper might be cost effective.

However, identification of an action was not highly successful. Further studies would be necessary for improving hit rate of identifying an action. One possible approach is applying an image recognition technique. We believe that such an image recognition technique can be applied to inferring driver "preparedness". We are conducting a formal and systematic experiment on this issue. The results would be shown in another paper.

It is also necessary to develop an integrated system according to the strategy shown in Figure 3. In a near future, we would like to develop a signal processing system which extracts the necessary data for each function from one pressure distribution sensor.

7. Acknowledgement

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