Towards a Smart Car Seat Design for Drowsiness Detection Based on Pressure Distribution of the Driver's Body

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Abstract—**Driver fatigue is a serious problem causing thousands of road accidents each year. The major challenge in the field of accident avoidance systems is the development of technologies for detecting or preventing drowsiness at the wheel. In this paper, we present a novel approach for fatigue estimation based on the design of an intelligent seat able to anticipate driver fatigue through analysis of driver's body pressure distribution.**

Keywords–Fatigue; Vigilance; Body pressure; Drowsiness; Smart seat.

I. INTRODUCTION

Fatigue and sleepiness during driving are considered as a dangerous phase that threatens road safety. The decreased level of alertness, generated by involuntary transition from wakefulness to sleep is responsible for a high number of accidents.

Among the factors that promote accident risk, we mention drowsiness at the wheel due to the lack of sleep, driving for long journeys and night driving. Hence, the need of a reliable driver drowsiness detection system, which can alert drivers before a mishap happens.

In literature, diverse approches have been used to develop monitoring systems. The first category is based on physiological studies like eyelid closure, electrooculogram (EOG), cerebral, muscular and cardiovascular activity [1].

The second category is the vehicle oriented approach based on driver performance and unusual behavior of the vehicle. Its principle is to analyze variations in the steering wheel movements, in the lateral position of the vehicle and in the velocity [2]. The last category contains algorithms based on analysis of visual signs. Here, the symptoms of sleepiness are legible through the driver's face appearance and eyes/head activity. For this approach, many types of cameras have been cited in the litterature. As an example, we cite visible spectrum camera [3], IR camera [4] and stereo camera [5].

In this paper, we introduce a new drowsiness detection system based on one of the physical concepts related to the driver's body which is the distribution of the pressure on the seat and its variation in time. Our contribution is to invent a smart seat for vigilance monitoring in order to detect fatigue and biomechanical distraction via recognition of sitting position by analysis of the driver's body pressure distribution on the seat.

The plan of the paper is organized as follows: Section II presents some models of intelligent car seat for fatigue detection. Section III describes our proposed approach for intelligent seat design. Section IV ends with a conclusion and discussion of possible perspectives.

II. STATE OF THE ART

Among the examples of smart seat whose purpose is fatigue detection, we cite the Hearken project (Heart And Respiration In-Car Embedded Nonintrusive Sensor). It is developed by researchers from the Institute of Biomechanics of Valencia (IBV, Spain) [6]. The seat can calculate heart rate and breathing rate of the driver [7]. The solution proposed in this project to address the stated need is a nonintrusive sensing system of driver's heart and respiration embedded in the seat cover and the safety belt of a car. It will detect the mechanical effect of heart and respiration activity, filter and cancel the noise and artefacts expected in a moving vehicle(vibration and body movements), and calculate the relevant parameters [8]. To do this, the seat and the seat belt are equipped with invisible sensors . They are integrated in the seat cover. Besides, there is the Ford Biometric Seat which takes into account the vital functions of the driver and the ambient temperature of the vehicle. It is able to assess the driver's breathing rate. It include a seatbelt that integrates piezoelectric film for monitoring breathing patterns. There are also two conductive sensors located on both sides of the steering wheel that measures the heart rate and stress level of the driver. There are also two infrared sensors on the steering wheel's faade, likewise on the area where the conductive sensors are located. These infrared sensors measure the temperature of both sides of the face and as well as both hands [9]. In addition, there is the Nottingham Trent project(University's Advanced Textile Research Group at Plessey). This seat project attempts to wake the driver up if he starts to fall asleep at the wheel. It is based on an Electrocardiogram (ECG) sensor system stitched into a car seat that measures the driver's heartbeats. If this starts to slow down, signifying sleep, an alert will be sent to the driver in order to wake him up [10].

Companies such as Daimler or Volkswagen are working on similar ideas that use sensor within the steering wheel or cameras. We notice that the common point between these systems is that they are all based on the analysis of the vital aspects of the driver (heart rate and respiration rate). They are different from our approach which will be detailed in the next section.

As a first impression, we tried to invent an independent fatigue detection mechanism of the vital aspects of the driver already mentioned, such as body temperature, heart rate, etc) to avoid the risk of confusion with the vibration of the car despite the accuracy of the sensors because this project is still in the testing phase. We think that other than the vibration of the car, there are the environmental impacts such as climate change (rain, wind,etc.), that may influence the performance of sensors accuracy (in case of violent wind). The friction of the wind on the car can change the values given by the sensors.

III. PROPOSED APPROACH

Fatigue is a gradual decline in physical and mental alertness that may lead to drowsiness and sleep. Driver fatigue is characterized by various indices such as fixed eyes, heavy eyelids, back pain, leg numbness and incessant need to frequently change the position, etc. These indices are considered as relevant signs that highlight the state of fatigue by many organizations of driving and road safety associations such as ECF (French driving school) [11] which is a member of IFSEN (International Federation of Networks of Education for Security) [12].

In our project, we are interested in exploiting the growing need for position change caused by fatigue or drowsiness during driving as it is indicated in Fig. 1:

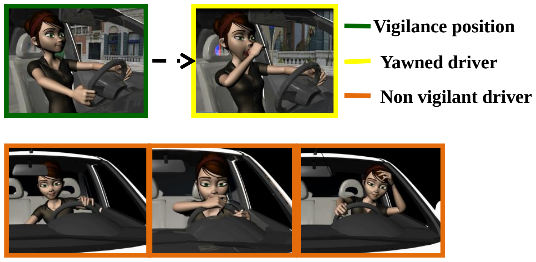


Figure 1. Examples of vigilant positions and fatigue ones

At the start of driving, the driver is usually vigilant. It adapts the good driving position (reference position). There should be no space between the seat and the driver's body. It must be "stuck" at the seat. However, he can't save this ideal driving position especially during long journeys and in special daytimes which promote fatigue and sleepiness [13].

The aim is to detect the fatigue and drowsiness state by analysis of pressure distribution change of the driver's body exerted on the seat. This change depends on the sitting position. It can be analyzed through a mesh of pressure sensors covering the seat surface. Fig. 2 mentions an illustration of this mesh of sensors.

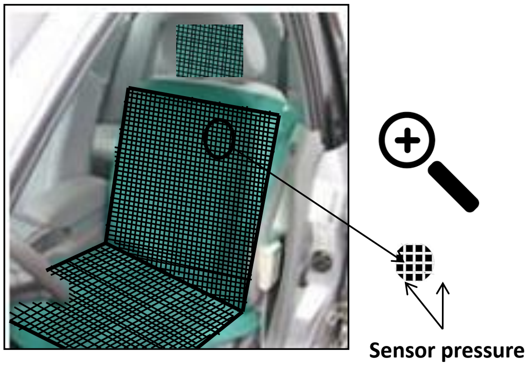


Figure 2. Mesh of pressure sensors

A. Interesting Seat Parts of Pressure Analysis

The most informative parts where the pressure change is more significant are the back cushion and the head support as indicated in Fig. 3. Indeed, our analysis is based on the 'all or nothing' rule (two states: zero pressure and high pressure) whose principle will be detailed in the next sections.

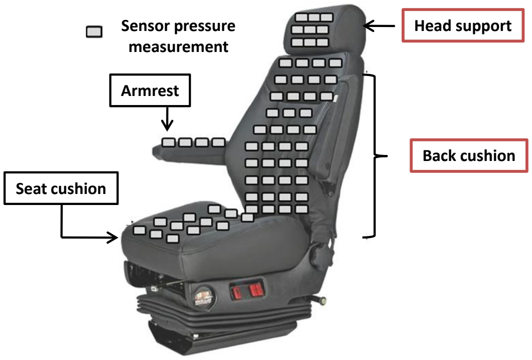


Figure 3. Different parts of the seat car

In the seat cushion, approximately there is only one state of pressure level (high value) because the weight of the driver's body is concentrated on this part whatever her position or her tilt's degree.

Regarding the efficiency of the pressure distribution on the armrest, it depends on the behavior of the driver(If he uses the armrest in case of right inclination or not).

By using specific embedded sensors, we can measure changes in driver's position during high activity and over long periods of time by analyzing the pressure changes over time.

B. Algorithm of Pressure Distribution Analysis

As we have already said, we will install a mesh of pressure sensors on the seat.

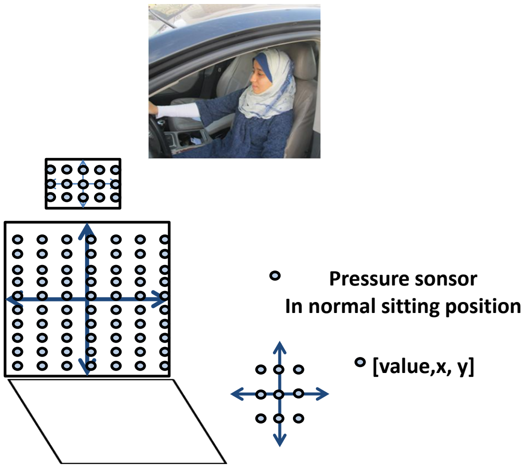


Figure 4. Reference sitting position

Each sensor is characterized by a specific address (x and y coordinates) and a value of force pressure as it is described in Fig. 4. The pressure is a fundamental physical concept. It can be seen as strength relative to the surface to which it applies. In mechanical field, pressure is defined locally from the component of the force normal to the surface on which it is exercised. If we consider an elementary surface dS with normal $\vec{n}$, undergoing a force $\vec{F}$, then the pressure p is defined by:

$$P = F/S \tag{1}$$

with

- F: applied force in newtons
- S: application surface in cm^2

1) Body's pressure variation on different vigilance state

Fig. 5, mentions examples of the pressure distribution of driver's possible sitting position. Other than the change of the seating position, this system allows us to recognize the driver's sitting position whether it is correct driving posture or not. For example, we notice for (P1) that the pressure distribution is approximately balanced on the seat's back cushion. For (P2), the left side is characterized by a high pressure value compared to that of the normal position, here the driver is moved more to the left side. The right part is characterized by a low pressure that may become null.

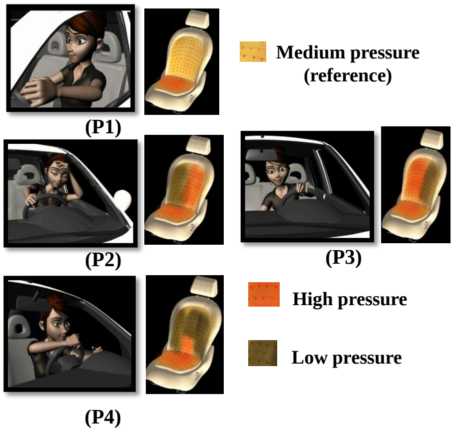


Figure 5. Examples of pressure distribution of some seating position

2) Right inclination

Fig. 6 indicates an example of pressure change in the case of right inclination.
After a tilt, there are areas in the seat where the value of the pressure becomes null because of the gap between some areas of the driver's body and the seat (there is no physical contact). We consider these notations as it is mentioned in the previous figure.

- black color: sensor with zero pressure
- yellow color: sensor with medium pressure (≤reference pressure)
- red color: sensor with high excess (>reference pressure)

As it is clear in the figure above, the pressure values vanish gradually from left to right by increasing the inclination degree. The black color dominates the left half of the sensor mesh but the right half is characterized by the dominance of red color (excessive pressure) because the body's weight is focused in this area. The recognition of inclination direction and degree may be known by analyzing the line sensor which represents the distance between the shoulders of the driver as it is explained in Fig. 7 : This figure shows the line of sensors at the shoulders of the cases (c)and (d) of the Fig. 6 and other intermediate states.

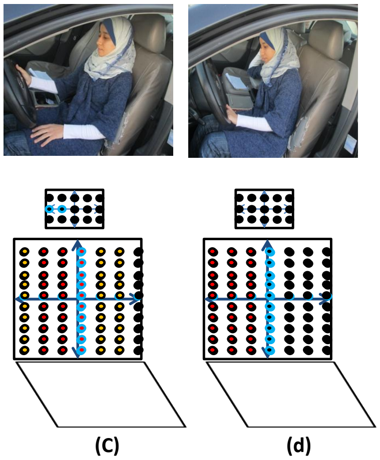


Figure 6. Cases of right inclination

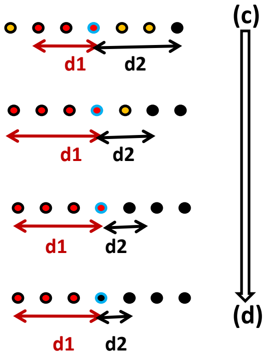


Figure 7. Characteristic distances of right inclination

- d1: distance between the vertical central dorsal axis and the farthest pressure sensor with high pressure in the right part
- d2 = distance between the vertical central dorsal axis and the nearest sensor with zero pressure in the left part

When d1 is bigger and d2 is smaller, the inclination degree increases

3) Left inclination

Fig. 8 mentions an example of body pressure distribution on the case of left inclination
In this case, the pressure values vanish gradually from right to left by increasing the inclination degree. This idea is perceptible at the surface which is the shoulder area, as it is indicated in Fig. 9.
Here, the meaning of the distances d1 and d2 which is different from that in the case of right inclination

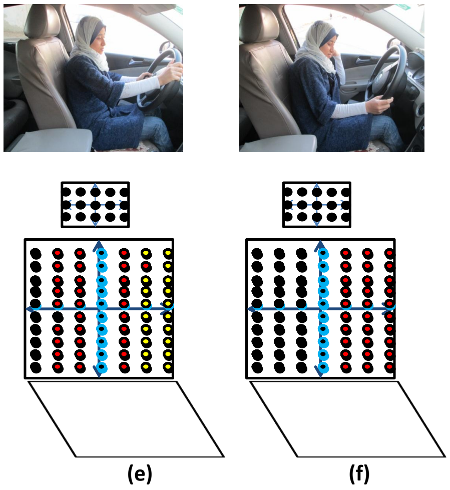


Figure 8. Cases of left inclination

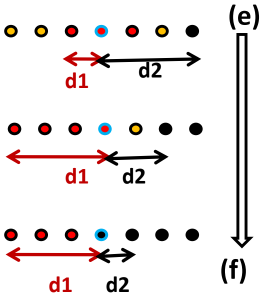


Figure 9. Characteristic distances of left inclination

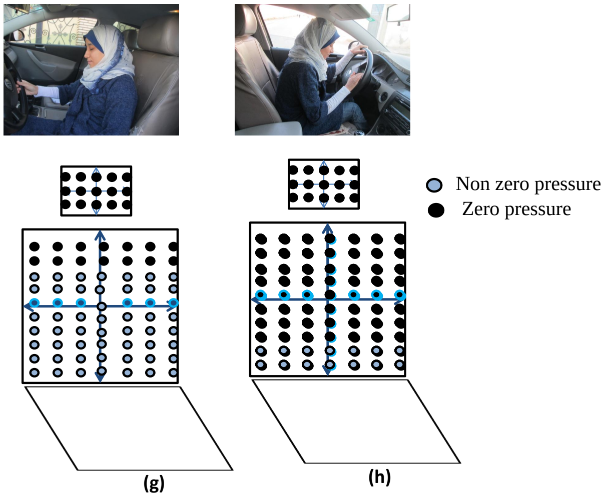


Figure 10. Cases of forward inclination

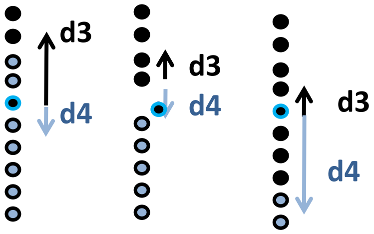


Figure 11. Characteristic distances of forward inclination

- d1 = distance between the vertical central dorsal axis and the nearest sensor with zero pressure in the right part
- d2 = distance between the vertical central dorsal axis and the farthest sensor with high pressure in the left part

4) Forward inclination
in Fig. 10, we cite an example for forward inclination
By increasing the inclination level (by moving from state g to h), the surface area with zero pressure becomes larger.

The following figure shows the distribution of pressure on the central column of the dorsal axis in various levels of inclination (cases (g) and (h) of figure 10 and another state). This idea is explained in Fig. 11.

- d3: distance between the center of the dorsal axis (horizontal axis) and the nearest zero pressure sensor (in the upper half of the back cushion)
- d4: distance between the center of the dorsal axis(horizontal axis) and the nearest non-zero pressure sensor(in the bottom half of the back cushion)

We note when d3 is smaller and d4 is bigger, the inclination degree increases.

Also, we note that in the head support there is no pressure (since no physical contact on this part in a forward inclination state). However, in a backward inclination case, it is possible that the pressure value at the head support increases compared to the normal state (reference position).

Fig. 12 shows different positions of the driver with or without contact with the head support.

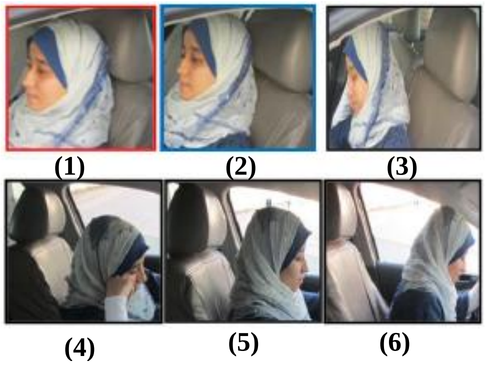


Figure 12. Head support in different driver positions

For example in image (1) which represents the reference position (vigilant state), the pressure distribution is balanced on the head support. However, in image(2), which shows a state of right inclination, there is a partial contact between the head and the head support. So approximately the left half of head support is characterized by zero pressure and the right half part is characterized by high pressure. For the rest of cases (4,5,6), we note that there is no contact at all with the head support.

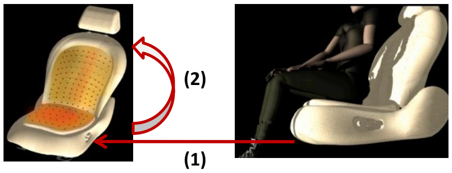
The pressure distribution at this seat component differs according to the seat's dimensions and the driver's size.

C. Characteristics of the smart seat

1) Automatic activation

The system is activated automatically, as soon as the driver sits on the seat, the system loads to define the study area as it is indicated in Fig. 13.

2) Optimized system for pressure analysis



(1) Weight sensing driver

(2) activation of pressure distribution system analysis

Figure 13. Automatic activation of the smart seat

We propose to add other algorithms that aim to optimize the data processing time (and thus the system response time) by the adaptation of analysis sensor surface which depends on the size of the driver. As soon as he sits on the seat, the system loads to define the study area according to the dorsal driver as it is mentioned in Fig. 14.

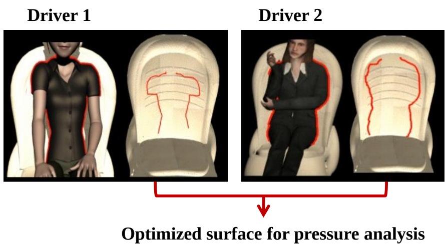


Figure 14. Illustration of the optimized system

D. Evaluation

A data collection is conducted in order to investigate whether different sitting position can be detected via analysis of body pressure distribution of the back of the driving seat. With a sheet sensors installed on the back of the driving simulator, pressure distribution is measured continuously in time, in which the pressure distribution can represent drivers posture. Four persons particpated in this study.

At this stage, three types of the actions were distinguished:

- Moving to the forward direction
- Moving to the left direction
- Moving to the right direction

The participant received five runs for data collection. The number of movements in a run differed from run to run depending on the sequence of the movements. The minimum was 8 and the maximum was 15 movements in each run.

The correct rate of movement detection was 100% for each driver (in general without specifying the movement direction).

This is done via a comparison between the pressure distribution of the reference position and other postions over time. If there is a change of the pressure's value of any other sitting position compared to the values of the reference position, we said that there is a driver movement.

In the following table (Table 1), we mean by RN the real number of a defined sitting position and GN mentions the generated number of recognized posture made by the smart seat in the test phase.

TABLE I. RESULT OF SITTING POSITION RECOGNITION FOR DIFFERENT MOVEMENT DIRECTION

		Driver 1	Driver 2	Driver 3	Driver 4
Right movement	RN	25	30	16	40
	RG	20	27	11	35
Left movement	RN	40	20	14	27
	RG	37	14	13	26
Forward movement	RN	19	36	15	20
	RG	17	34	14	19

The global recognition rate of different sitting position is mentioned in Fig. 15.

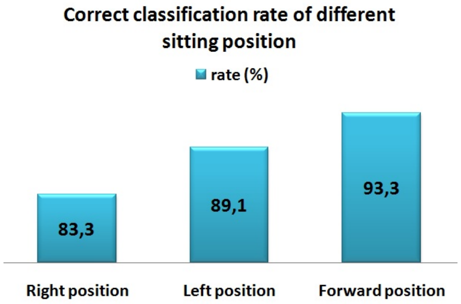


Figure 15. Global recognition rate of different sittig position

We aim to maximize the types of movements that can be recognized by the seat by adding other sitting positions to the three postures already mentioned.

E. Discussion

This approach allows us to detect the inclination's direction and degree of the driver in real time by comparing the distances d1 with d2 and d3 with d4. Thus comparison between the number of active sensors (non-zero pressure) with those at zero pressure).

Also, seeing that fatigue is characterized by incessant need of position change, we can calculate the frequency of position change which is equal to the number of inclinations times in a given time interval.

To differentiate the change in normal position (slight inclination) to those which denote fatigue or drowsiness, we must add the constraints of threshold and time which is the subject of our next work. If a specific threshold is reached (which is fixed experimentally and by medical experts), a timer will be triggered to calculate the inclination duration.

Added to that, in a previous work we have developed a drowsiness detection system based on a video approach by calculating eye closure duration using a classification system of eyes states based wavelets networks [14]-[18] and we have another system of vigilance measurement based on head posture estimation.

So it is possible to design a multi-parameter system based on pressure distribution,eyes blinking analysis and head position recognition [19].

The different sitting positions mentioned in the paper are just examples of the most common cases of drivers in general. Of course there are various other positions, but the principle is to follow the variation of the pressure distribution by analyzing the variation in the behavior of the sensors relative to the central axis of the seat. So, whatever the obtained position, its recognition takes place by applying the same principle. May be there are positions where there is a risk of recognition confusion, but we aim to generalize our approach on the maximum seating positions even with different degree of accuracy.

IV. CONCLUSION AND FUTURE WORKS

We propose a new method for fatigue estimation based on a design of a smart seat car using pressure sensors to analyse the pressure distribution of the driver's body in the time. Our method is different to those already cited in section II which exploit vital aspects of the driver, such as heart and breathing rate. Here, we exploit a physical concept which is the pressure force. The objective of this seat is to monitor driver's vigilance via sitting position recognition.

We aim to develop a multi-parameter vigilance monitoring system by combinig the previous systems already cited in the dicsussuion section.

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