# An Occupant Sensing System for Automobiles Using a Flexible Tactile Force Sensor

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**ABSTRACT** With a view to upgrading the functions of automotive safety systems and driver assistance technology, work is going forward on the development of sensors to make judgments of seat conditions, including the body build of the occupant, and the presence or absence of a child restraint system. Particularly in the U.S. there are demands to reduce injuries inflicted by air bags, and this requires sensors that detect occupant body build, posture, etc. Using a flexible tactile sensor, we have measured data for load distributions applied by car seat occupants and have investigated a method of classifying occupants by body build.

We have verified the accuracy of a method for judging the standing body height of occupants based on peak distance and buttock print width as shown by the loads applied to the seat, and have found that in discriminating between adults and children, an accuracy of about 90% can be obtained.

## 1. INTRODUCTION

To enhance automobile safety, supplemental restraint systems (SRS, more commonly known as air bag systems) have come into wide use in recent years and a variety of technologies including seat-belt pretensioning and force limitation are being adopted. In the United States, however, fatal accidents caused by air bags have also been reported and the U.S. Department of Transportation's National Highway Traffic Safety Administration has called for development of a safer air bag [1] having reduced potential for causing injury. With such a smart air bag system, air bag deployment should be regulated by such factors as the severity of the impact and the seating configuration (whether a child restraint system is installed, the build and posture of the occupant, seat position, etc.), and determining these requires sensors. A number of sensing methods--electric field [2], infrared [3], etc.--have been proposed, and their advantages and disadvantages are known.

Accordingly we have developed a flexible tactile sensor suitable for use in an in-vehicle environment. We are also studying the feasibility of a system in which judgments of body build and so on are made from data on the distribution of occupant load on the seat, and herewith report on a prototype occupant sensor system using load distribution data.

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## 2. DETERMINING BUILD WITH A FLEXIBLE TACTILE SENSOR

Flexible tactile sensors are used for electronic keyboard instruments and in medical instrumentation applications, and are similar in structure to the membrane switches found in computer keyboards. The difference lies in the fact that whereas a membrane switch has only two positions--on and off--the flexible tactile sensor has electrodes of pressure sensitive ink so that the electrical resistance between electrodes varies continuously in accordance with the pressure applied to the electrode. Like membrane switches, flexible tactile sensors can be configured by screen printing in a wide variety of patterns, and can be installed in currently used car seats without the need for major structural modification. They are also so thin and supple that, when installed between the urethane foam

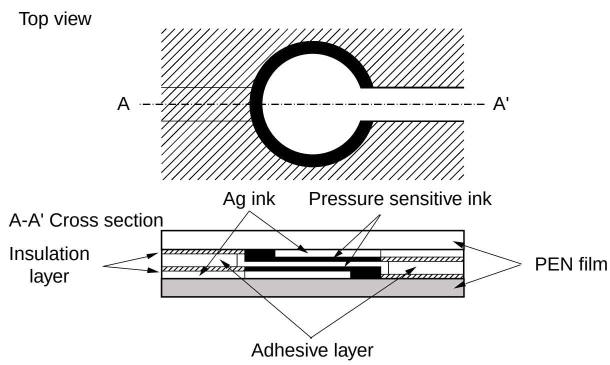


**Figure 1 Schematic drawing of a flexible tactile sensor**

and the cover, their presence is not noticeable to the occupant.

The in-vehicle flexible tactile sensor developed in this study uses a polyethylene-naphthalate (PEN) base film. Figure 1 shows a top view and cross section of a pressure-sensitive point. The electrodes at the pressure-sensitive points are approximately 10 mm in diameter and the sensor has an overall thickness of about 0.2 mm. An insulating layer is printed over the silver ink circuitry, preventing migration of the silver. There is also a gap between the electrodes at the pressure-sensitive points, so that when the air in the gap expands or contracts with the atmospheric temperature, the minimum pressure required to activate the flexible tactile sensor changes. An air outlet is therefore provided (not shown here) as in the case of a membrane switch.

As Figure 2 shows there is an inversely proportional relationship between the resistance of the flexible tactile sensor and the pressure applied, and it is dependent of atmospheric temperature. Sensitivity is determined primarily by the composition of the pressure-sensitive ink, the type and thickness of the base film and the structure (electrode area and gap) of the sensor cell. The main reason for the temperature dependence is thought to be that the stiffness of the base film and pressure-sensitive ink changes in accordance with the ambient temperature.

Changes in the resistance of the flexible tactile sensor are read out using the inverting amplifier circuit of an operational amplifier (see Figure 3), and $R_s$ indicates the resistance of the pressure-sensitive point. There is an inversely proportional relationship between the pressure applied to this point and its resistance (Equation 1), and the output voltage $V_{out}$ of operational amplifier is inversely proportional to the pressure $P$ applied to the pressure-sensitive point

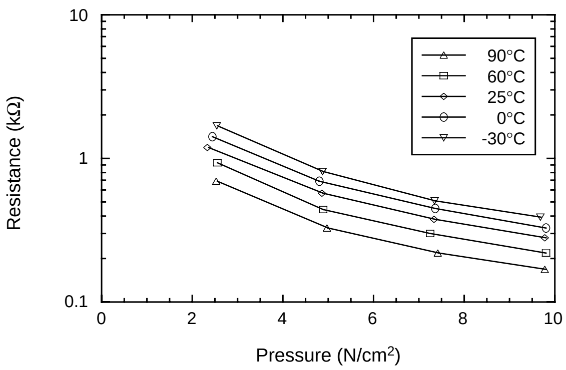


**Figure 2 Sensor performance**

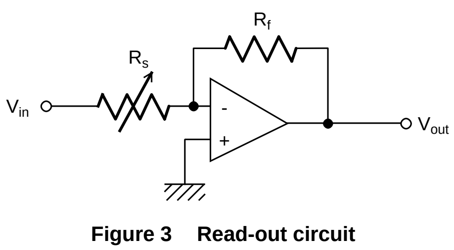


**Figure 3 Read-out circuit**

(Equation 2). It is thus possible to find the pressure on the pressure-sensitive point simply by reading the voltage.

$$A = R_s \cdot P \tag{1}$$

where:

$A$ is sensitivity,

$R_s$ is the electrical resistance of the pressure-sensitive point, and

$P$ is the pressure applied to the pressure-sensitive point.

$$V_{out} = -V_{in} \cdot (R_f / R_s)$$
$$= -V_{in} \cdot (R_f / A) \cdot P \tag{2}$$

where:

$V_{out}$ is the output voltage of the operational amplifier,

$V_{in}$ is the input voltage of the operational amplifier, and

$R_f$ is the feedback resistance

Next let us consider the method by which occupant body build is judged using the flexible tactile sensor.

Taking first the traditionally adopted method in which judgments are based on the load applied to the seat cushion,[4] we may expect to find a correlation to body weight as long as the seated posture remains unchanged, but this poses a problem in that the load on the seat cushion varies with backrest angle. Another problem is that with small children their feet do not reach the floor, while with adults some of the load bears on their feet and the floor, so that estimating body weight simply from the load on the seat cushion introduces a large error. Additional problems in measuring load using a flexible tactile sensor include the temperature dependence of the sensor itself, and the temperature and humidity dependence of the stiffness of the urethane foam used for the seat cushions, as well as its deterioration over time.

Accordingly a flexible tactile sensor mat consisting of a large number of pressure-sensitive points arranged in a 2-dimensional matrix was installed between the urethane foam and the cover of the seat, and the relationship between load distribution data obtained from measurements of the pressure applied to all pressure-sensitive points and the parameters of body build were observed. Figure 4 shows a typical load distribution applied to the seat cushion when a person is seated. Note the twin pressure peaks beneath the buttocks. It is known that these pressure peaks appear below the ischial tuberosities, and it has been reported by Mizukami et al.[5] that no significant correlation can be found between the peak value and the Rohrer index (which indicates standing body height, body weight, degree of adiposity), or the maximum thigh circumference. This is because the shape of the ischial tuberosities become tapered and narrow toward the front (tip), so that the area in contact with the surface of the seat varies according to the angle between the surface and the pelvis, thereby causing the peak value to change. This makes it difficult to estimate body weight of the occupant from the measured peak values.

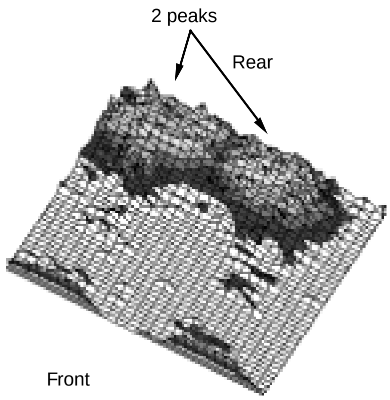


**Figure 4 Typical load distribution**

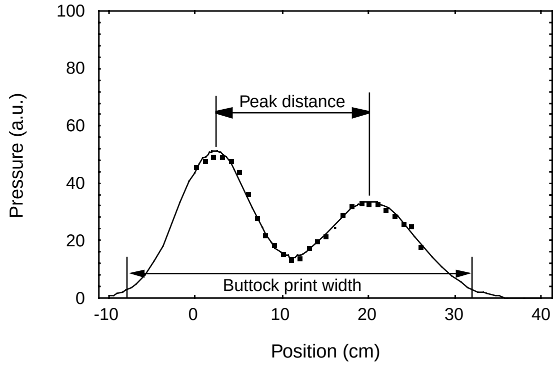


**Figure 5 Typical pressure profile**

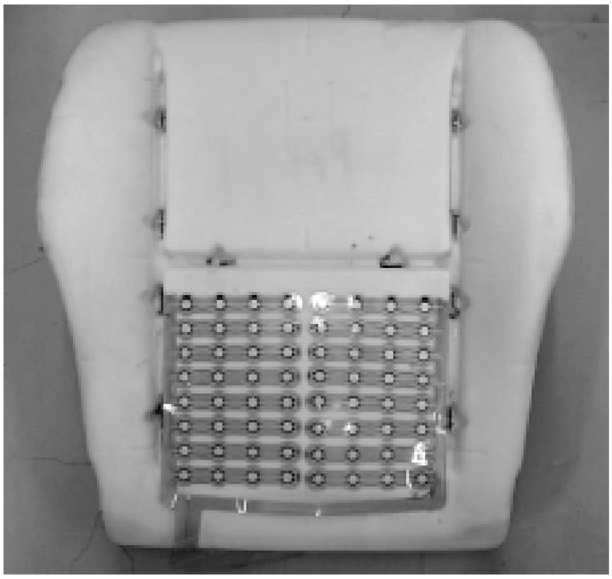

**Photo 1 Installation of flexible tactile sensor mat**

Turning then to the relationship between skeletal structure and the parameters of body build, wide use has been made in Japan of Fujii's equation for estimating standing body height[6] with respect to all the long bones based on a recursive linear equation. Reports have also been made on estimating standing body height by measuring the length of the vertebral column,[7] but with respect to the relationship that concerns us here between the lower pelvis and parameters of body build, it has been reported by Kochi et al.[8] that there are major gender and individual variations. In terms of the relationship between buttock size and parameters of body build, it is known that there is a correlation between seated hip breadth and body weight.

Accordingly we investigated the relationship between the distance between the two characteristic peaks observable below the ischial tuberosities (hereinafter referred to as the "peak distance") and the standing body height of the occupant, and the relationship between the width of the area subjected to pressure (which is associated with seated hip breadth and is hereinafter referred to as "buttock print width" and the body weight of the occupant. We also present some discussion of the accuracy of estimates of the standing body height and body weight of occupants derived from these parameters.

## 3. EXPERIMENTAL

Reducing the pitch between pressure-sensitive points will provide more data on load distribution, but this requires expanded interface circuitry between the flexible tactile sensor and the signal processor, making the system too bulky and expensive for in-vehicle use. With an eye to feasibility, what was required was the capability of judging the parameters of occupant body build with the smallest possible number of pressure-sensitive points.

Figure 5 shows the pressure profile for pressure-sensitive points on a straight line passing through the two pressure peaks in Figure 4 and spreading out to left and right. Points shown in the figure represent the data measured for the pressure-sensitive points, and solid lines represent the results of approximations using approximation curves. We undertook to reorganize the relationship between these approximation curves and the parameters of body build, or, in more concrete terms, taking the distance between the two peak positions on the approximation curves as the peak distance and taking the distance between the lower reaches of the peaks that spread out to left and right as the buttock print width, the relationship between standing body height and body weight.

The objective of the experiment was to investigate the relationship between buttock size and parameters of body build. A flexible tactile sensor mat with 64 pressure-sensitive points arranged in an 8x8 matrix at a pitch of 2.5 cm front-to-rear and 3 cm left-to-right was installed in a compact sedan, between the urethane foam and the cover of the passenger seat, in the area where the buttock would come when the occupant was seated (see Photo 1).

In the experiment, load distribution measurements were made by having test subjects ride in a vehicle having a sensor-equipped seat. The test subjects comprised 212 men and women aged 3 to 65. Adult subjects were permitted to adjust the back rest and slider to their liking and were given no guidance regarding posture. Children, on the other hand, were directed to sit so that, at a standard back rest angle, their buttocks went deep into the seat. After an adult test subject got in, the car was driven about 300 m at a speed of 10 km/hr, after which, with the car stopped and the engine on, the load distribution data was collected. When the subject was a child, data was collected without moving the car (engine off). The standing body height and body weight of the subjects were measured immediately before they got in the test vehicle. Height and weight were measured with shoes of; weight was measured with clothes on.

Data on those subjects who sat too far forward or were otherwise placed their buttocks outside the area with sensors was excluded. Figure 6 shows the relationship between the peak distance found from approximation curves and the standing body height for the remaining 166 subjects. It can be seen that as peak distance increased, there was a linear increase in the height of the subjects. There was also a gender-based difference in the adults. A recursive straight line was obtained for the data, and it was found that in estimating standing body height from the peak distance using that recursive equation, the difference between estimated height and actual height represented a standard deviation of 11.6 cm.

Figure 7 shows the correlation between the buttock print width and body weight as obtained from approximation curves. It can be seen that as buttock print width increases, there is a linear increase in body weight. And for weight, as for height, there was a gender-based difference in the adults. A recursive straight line was obtained for the data, and it was found that in estimating body weight from the buttock print width, the difference between estimated weight and actual weight represented a standard deviation of 9.5 kg.

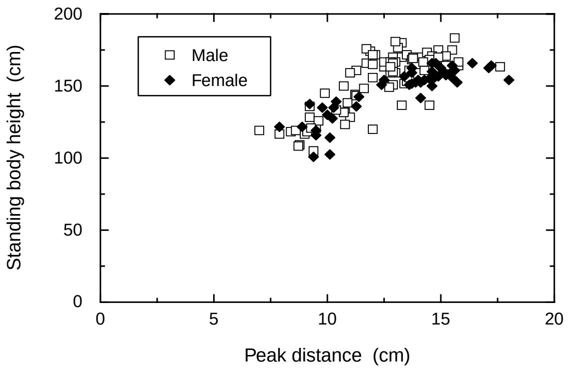


**Figure 6 Correlation between peak distance and standing body height**

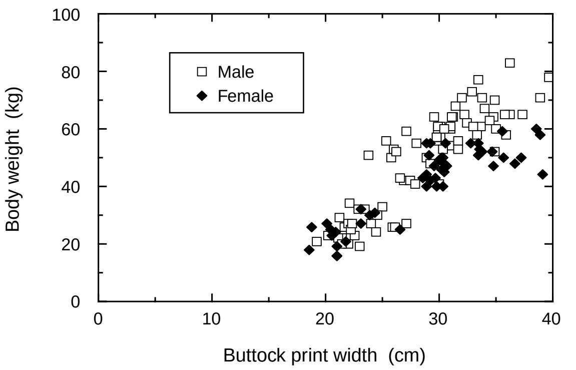


**Figure 7 Correlation between buttock print width and body weight**

## 4. DISCUSSION

Here we estimated the accuracy of judgments for adults and children from results obtained with the test equipment, using the size of crash test dummies as standard. The method of classification by body build was to determine classification probabilities for the standing body height and weight of occupants from the standard deviation for differences in intermediate values for height and weight of crash dummies as class boundaries, with respect to four classes:

- Class 1: child up to 3 years old
- Class 2: child up to 6 years old
- Class 3: female of slight build
- Class 4: male of average build

Figure 8 shows the results of a determination of probability of occupants being classified in any class by standing body height, as estimated from peak distance. From this graph we see, for example, that when an adult about 150 cm in height sits down, the probability of being classified in the four classes is:

- Class 1: 0.01%
- Class 2: 9.10%
- Class 3: 74.77%
- Class 4: 16.12%

Figure 9 shows the results of a determination of classification probability by weight, as estimated from buttock print width. From this graph we see, as in the case of standing body height, that when an adult weighing about 50 kg sits down, the probability of being classified in the four classes is:

- Class 1: 0.10%
- Class 2: 9.38%
- Class 3: 84.11%
- Class 4: 6.41%

Table 1 shows the results of analogous calculations for standing body heights and weights corresponding to the other crash dummies.

These results showed that taking those the same size as or smaller than the 6-year-old dummy as children, and those the same size as larger than the light-build female dummy as adults, an accuracy of about 90% could be anticipated in distinguishing children and adults, irrespective of which algorithm--peak distance based or buttock print width based--was used.

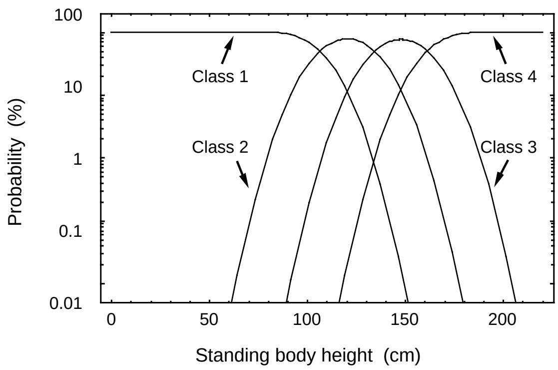


**Figure 8 Probability curves for classification calculated from experimental results for peak distance**

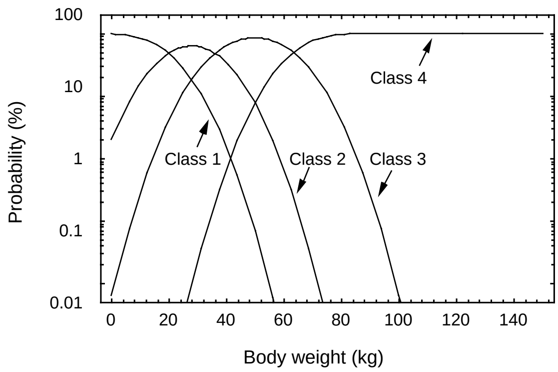


**Figure 9 Probability curves for classification calculated from experimental results for buttock print width**

**Table 1 Probabilities for classification of occupants of different size**

| | Probability (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Peak distance | | | | Buttock print width | | | |
| | Class 1 | Class 2 | Class 3 | Class 4 | Class 1 | Class 2 | Class 3 | Class 4 |
| 3 year old child dummy | 85.90 | 14.08 | 0.02 | 0 | 68.16 | 30.64 | 1.20 | 0 |
| 6 year old child dummy | 14.10 | 76.79 | 9.10 | 0.01 | 31.84 | 58.68 | 9.48 | 0 |
| 5 percentile American female dummy | 0.01 | 9.10 | 74.77 | 16.12 | 0.10 | 9.38 | 84.11 | 6.41 |
| 50 percentile American male dummy | 0 | 0.05 | 16.07 | 83.88 | 0 | 0 | 6.41 | 93.59 |

## 5. CHILD RESTRAINT SYSTEM POLICY

With child restraint systems now being compulsory, it becomes of practical importance in classifying the occupant in the passenger seat to determine whether a child restraint system is installed or not. Car manufacturers recommend that for reasons of safety, that child restraint systems be installed in the back seat in cars equipped with a front passenger air bag, but it is always possible that motorists will install the child restraint system in front.

Figure 10 shows an example of the load distribution when a child restraint system is in place. Note the significant difference in load distribution compared to when a person is seated. We therefore examined whether it was possible to discriminate between a person and a child restraint system or other object occupying the seat. Using the test equipment, load distribution data was collected when the seat was occupied by a child restraint system, a sandbag or a briefcase. Half of the data, combined with the data on human occupants (see previous section) was used as learning data for a neural network. When the remaining data was fed to the neural network and results obtained, it was found that accuracy for the experimental data of this study was about 90%. There are, however, a number of problems to be considered when using the learning function of a neural network.

One is that the accuracy of judgments varies according to how the data used as learning data is defined, and, given the innumerable types of child restraint system now on the market, it is a practical impossibility to develop a neural network that encompasses all of them. What is more, as new types of child restraint systems are brought to market, there is a high probability that neural networks that only take account of the older types will produce errors, so that motorists will not be able to use the new child restraint systems. Judgment methods incorporating pattern learning and fuzzy rules have also been considered,[9] but it is our opinion the algorithm that discriminates between persons and objects by the relationship between the points at which the pressure peaks are observed and the load data in the vicinity of the peaks is superior.

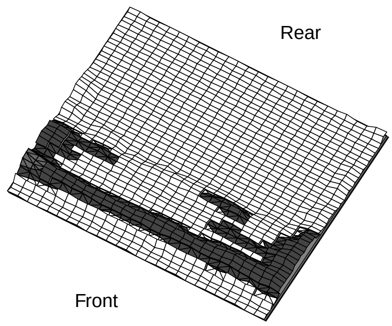


**Figure 10 Typical load distribution with child restraint seat on seat cushion**

## 6. CONCLUSION

We have developed an flexible tactile sensor capable of being used in an in-vehicle environment, and have considered a method for determining the body build of a seat occupant on the basis of data on load distribution from the sensor. It was found that in classifying occupants into two classes--child or adult--using the method of judgment considered, an accuracy of about 90% could be anticipated.

Using a prototype incorporating an algorithm for classifying occupants by body build and an algorithm for distinguishing a child restraint system or other object, we intend to verify the effect of the occupant's posture and the determination of when a child restraint system or other object is placed on the seat, examining the accuracy of judgments made under field conditions, thereby proceeding to clarify problems relating to practical use.

## ACKNOWLEDGMENTS

In developing the flexible tactile sensor, Atsushi Ueda and Masahiro Hatsuta of the RETS Division, Nitta Corp. worked on the pressure-sensitive ink and the structure of the sensor. In developing the judgment algorithms, we received many suggestions from Ken'ichi Arai of the Science and Technology Center, Furukawa Information Technology Co., Ltd. relating to the application of techniques of pattern recognition. In constructing the testing equipment, Tatsuya Fujisaki and Toru Tomai of the RETS Division, Nitta Corp. extended their cooperation for hardware design and software development. In developing the prototype, we received cooperation from Yasuhiro Arima of the Science and Technology Center, Furukawa Information Technology Co., Ltd.

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