International Journal of Automotive Technology, Vol. 7, No. 7, pp. 827–832 (2006)

1229–9138/2006/031–09

DEVELOPMENT OF OCCUPANT CLASSIFICATION AND POSITION DETECTION FOR INTELLIGENT SAFETY SYSTEM

M. A. HANNAN[1)*], A. HUSSAIN[1)], S. A. SAMAD[1)], A. MOHAMED[1)], D. A. WAHAB[2)] and A. K. ARIFFIN[2)]

[1)]Department of Electrical, Electronic & Systems Engineering, Faculty of Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor DE, Malaysia
[2)]Department of Mechanical & Materials Engineering, Faculty of Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor DE, Malaysia

(Received 26 May 2006; Revised 4 October 2006)

ABSTRACT–Occupant classification and position detection have been significant research areas in intelligent safety systems in the automotive field. The detection and classification of seat occupancy open up new ways to control the safety system. This paper deals with a novel algorithm development, hardware implementation and testing of a prototype intelligent safety system for occupant classification and position detection for in-vehicle environment. Borland C++ program is used to develop the novel algorithm interface between the sensor and data acquisition system. MEMS strain gauge hermatic pressure sensor containing micromachined integrated circuits is installed inside the passenger seat. The analog output of the sensor is connected with a connector to a PCI-9111 DG data acquisition card for occupancy detection, classification and position detection. The algorithm greatly improves the detection of whether an occupant is present or absent, and the classification of either adult, child or non-human object is determined from weights using the sensor. A simple computation algorithm provides the determination of the occupant's appropriate position using centroidal calculation. A real time operation is achieved with the system. The experimental results demonstrate that the performance of the implemented prototype is robust for occupant classification and position detection. This research may be applied in intelligent airbag design for efficient deployment.

KEY WORDS : Sensor, Occupant classification, Position detection, Intelligent safety system

1. INTRODUCTION

Enhancement of vehicle occupant safety is an important research area in the automobile industry (Devy *et al.*, 2000). It is therefore necessary to increase the quality of the vehicle components to ensure the safety and comfort of the occupants. Occupant detection and characterization are considered related to safety issues. According to Gautama *et al.* (1999), detection and classification of seat occupancy open up new ways to improve the safety and comfort features of the occupants. Therefore, a reliable occupant detection and classification system can make intelligent safety system in automobile applications (Timothy and Trivedi, 2003). In general, the detection and distinguishing of a particular class of occupant from all others is a difficult task.

Over the years, a variety of functions have been developed to improve vehicle safety system such as occupant detection and classification. Despite the success of some of these systems in constrained scenarios, the general task of detection and classification still pose a number of challenges with respect to sensors for data acquisition, real time implementation and operation (Shigeyuki, 2004). In the automotive environment, occupant detection and classification are based on signal and image processing approaches. We limit our prototype experiments to the signal processing approaches.

However, a comprehensive survey of dynamic scenes for occupant detection and classification methods can be found. Some recent occupant sensing approaches are based on vision sensors, where measurements of infrared and ultrasonic beam are used for detection, classification and position detection of the occupant (Owechoko *et al.*, 2003). However, these systems drawback's are not able to capture the entire seat and are unable to distinguish between certain occupant types and positions due to limited representation of the occupant (Krotosky *et al.*, 2004). Devy et al. introduced the stereo vision integrated 3D sensors on the vehicle cockpit in order to detect and

**Corresponding author.* e-mail: eehannan@vlsi.eng.ukm.my

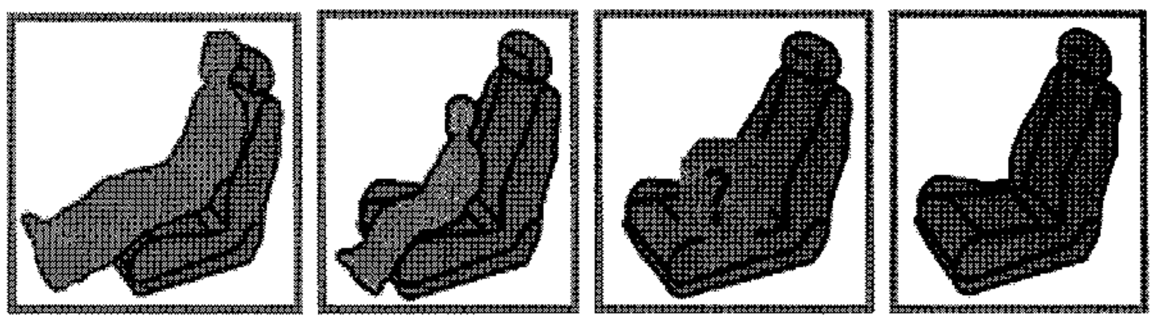

Figure 1. Examples of vehicle occupancy classes.

classify passenger seat occupancy (Devy *et al.*, 2000). The performance of these 3D sensors is good enough to tackle weak real time constraints, and provides dense and accurate reconstruction. However, an extra illuminator is needed to project a structured light on the passenger seat and the acquisition process in a complex situation can not be identified.

To overcome the illumination problem and to acquire data from the interior of the vehicle, Timothy *et al.* 2003 introduced a real time camera based on stereo algorithm. This type of algorithm is well suited for in-vehicle as it can change the intensity of the posture on demand, and the associated occupant scene can be localized and tracked using relatively fast techniques (Krotosky *et al.*, 2004). The problem of the system is that it will fail to correctly track the torso of the occupant if the occupant's feet are on or near the dashboard.

Occupant variation problems on the seat have a lot of effects on detecting and classifying in real time applications. Even if two occupants belong to the same class, they can differ in size, sex, race, pose, haircut, clothes and whether if there are glasses, beard or headgear present (Klomark, 2000). To overcome these problems, a weight sensing method based on MEMS sensor signals has been developed to detect the occupant presence, classify accordingly as either adult or child and further detect for possible off positioning. Figure 1 depicts the possible occupant classes as a result of such occupant classification system (Bob, 2005).

This paper describes a novel weight sensing intelligent system of MEMS sensor technology using a PCI data acquisition card. An interfaced algorithm is developed with a Borland C++ program for sensor output and the PCI card. The detection and classification of an occupant or non-human object is done by the weight sense from the sensor hardware architecture, and the evaluation of the position of the occupant is determined through the centroidal calculation of the sensor output. It is demonstrated that real time operation can be achieved with this system.

This paper is organized as follows: an overall system description of our approach is introduced in section 2 mentioning the sensor topology, interface algorithm and computational structure. Section 3 describes the operating principle. Experimental results and discussions are viewed in section 4 while the conclusions are drawn in section 5.

2. SYSTEM DESCRIPTION

This section explains the overall architecture of this intelligent safety system for occupant classification and position detection in a vehicle as shown in Figure 2. The main system consists of the sensor topology, interface algorithm and computational structure. The sensor topology describes the prototype of the MEMS sensor layout inside the vehicle seat to gather data information. The interface algorithm optimized the sensor output data through PCI-9111 DG data acquisition card (NuDAQ, 2000). The computational structure is the centroid calculation process in the interface program that is used to find the occupant position. This robust detection and classification system will be described in detail below.

2.1. Sensor Description

Many types of sensors are used by placing one on each corner of the seat in current researches for occupant detection system like pressure sensor, distributed load sensor and load cell (John, 2000; Jeff and Candace, 2005; Bob, 2005). As shown above in Figure 2, F1, F2, F3 and F4 represent the layout of the four sensors that make up the intelligent sensor system. This intelligent sensor system is mainly based on Silicon MEMS strain gauge hermatic pressure sensor which is glass bonded to a stainless steel diaphragm. They are designed to operate with a 5 volt DC supply with rating of 0–100 kg to provide a linear output voltage of 0–5 volt DC (MSG, 2005).

The connector is designed with a 3 pin configuration of supply voltage, ground and output voltage. The analog output of the sensor feeds to the data acquisition card with programmable input ranges to provide the decision. The hermetic design caters for temperature compensation, accurate performance, self-diagnostic capability and compatibility with almost any media.

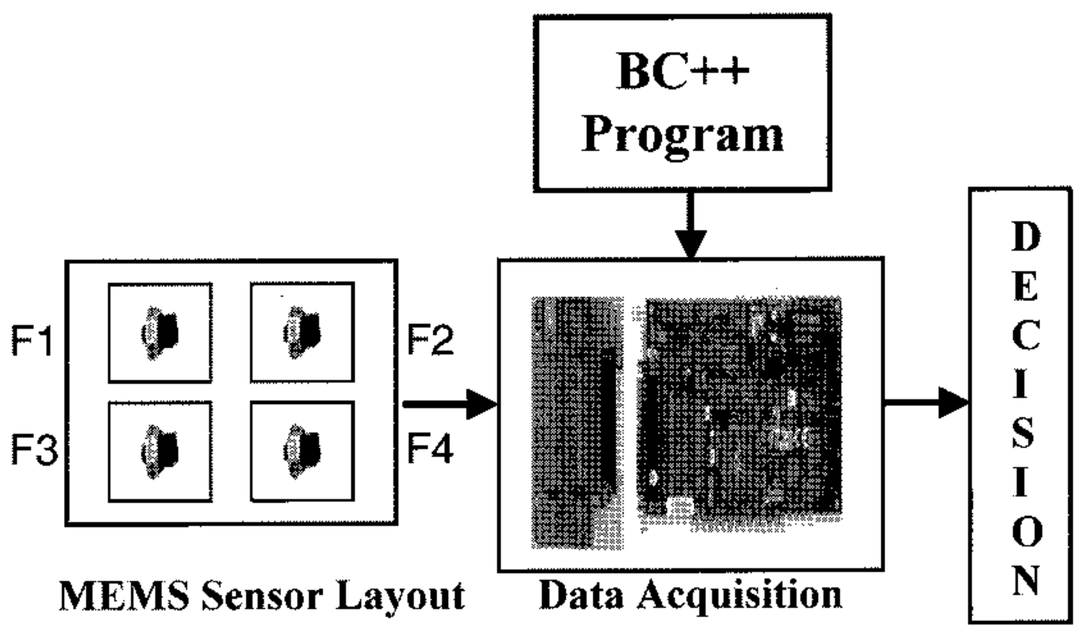

Figure 2. System architecture for overall detection and classification.

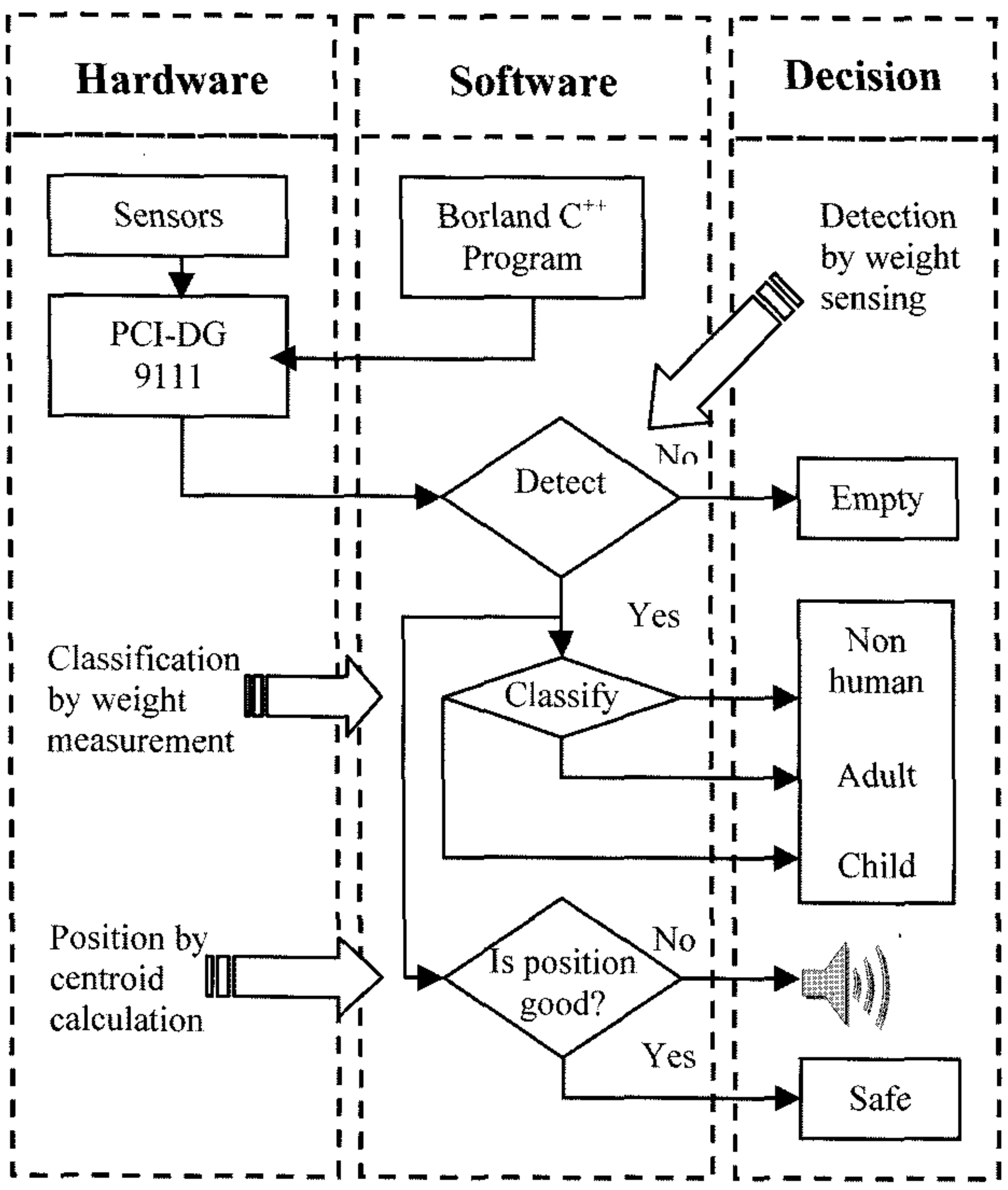

Figure 3. Software and hardware interfacing diagram.

2.2. Interface Algorithm

The interface algorithm between the software and hardware is developed based on a Borland C++ program. Figure 3 shows the interface diagram between the software, hardware and the display unit. In this interface, data are acquired from the sensor through PCI-DG 9111 using BC++ program. The program firstly determined whether the seat is empty or whether something is on it according to the four measured weight sense. In order to classify, the weight measurement data are used with logic combination. We consider that less than 10 kg as a non-human object, while the child setting is '10 kg < child < 35' and the adult setting is 35 kg < adult < 100 kg. For example, when an adult occupant is on the seat, the adult logic is true, and child and non-human object logics are false, which the dynamic output classifies as adult and displays its decision on the monitor. Next, the occupant torso movement is determined by the centroidal calculation of the weight measurement, to check whether the occupant upper body is in good position or not. Currently, in our interface algorithm, we do not consider the infant in the front seat because according to the National Safety Council (NSC) in America and other research results, (AAP, 2006; NSC, 2005; Stephen, 2005) infants using safety seat on the back passenger seat facing rear are safer than that of front seat with passenger airbag. However, the non-human object calculation is based on less than 10 kg and without positional variation.

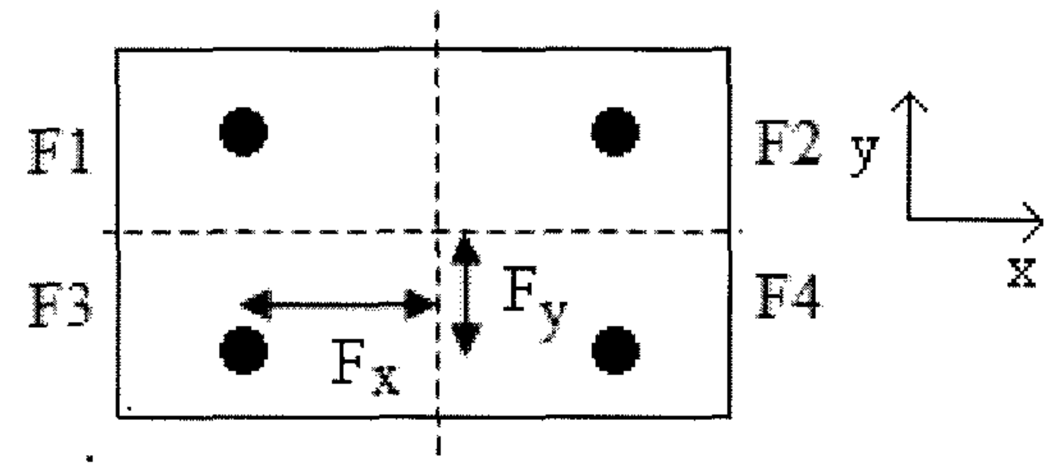

Figure 4. Calculation of the occupant position by Centroid.

2.3. Computational Structure

In our interface algorithm, the computational structure mainly involves only two calculations namely, weight forces and centroidal distance for occupant classification and position, respectively. We do not consider any belt tension, because at any situation, whatever the motion, weight on the sensor and centroidal distance are sufficient for position calculation. For example, in a frontal crash, surely the passenger weight will be moved at the front direction. Accordingly, each sensor will provide its weight, therefore the front sensors weight may be higher. Based on this specific situation's weights, the interface algorithm provides exact classification and position decision. Sensors are placed on the seat as shown in Figure 4.

The centroid distance from the center of the seat in the y direction, Fy, is the sum of these forces times the distances divided by the total force. The horizontal position, Fx, can be calculated in the same manner. The equations are as followed:

Centroid of x axis $Fx = x\dfrac{(-F1+F2-F3+F4)}{(F1+F2+F3+F4)}$

Centroid of y axis $Fy = y\dfrac{(F1+F2-F3-F4)}{(F1+F2+F3+F4)}$

where F1, F2, F3 and F4 are weight forces of the four sensors, while x and y are the distances from the centre to the sensor in x and y directions, respectively.

These calculations of Fx and Fy also provide the appropriate position of the occupant. In the above centroid calculation, the positive and negative values of Fx indicate that the occupant is bending towards the right and left, respectively. Similarly, positive and negative values of Fy indicate that the occupant upper body is leaning towards the front and back, respectively. However, a zero value for Fx and Fy indicates that the occupant is sitting up-right in a perfect condition. As an example, if the values of F1, F2, F3 and F4 are 10, 12, 13 and 14, respectively then the centroids from the x and y axes, are Fx, which is x (3/49) and Fy, which is y(–5/49. These values imply that the occupant's torso is leaning to the right and resting his back on the seat. In addition, if the occupant torso is leaning either too much towards the front, right or left, these also indicate that the occupant is not in the safe position for airbag deployment.

3. OPERATING PRINCIPLE

The Texas Instruments 3P88 is a silicon MEMS strain gauge hermatic pressure sensor containing micromachined integrated circuits. The device consists of micromachined weight sensing and a signal conditioning circuit with filters integrated in a single package. The sensing element is sealed hermetically at the stainless steel diapharm using a bulk micromachined strain gauge. The sensor measures the weight of the occupant and extracts the weight from the sensor sensing element through data acquisition. The signal conditioning circuit with filters provides a high level output voltage that is ratiometric and proportional to the weight sense. The filter is used to make sure that there is no requirement for external passive components to set the cut-off frequency. Ratiometricity simply means the output analog voltage and sensitivity will scale linearly with applied force of weight. That is, as the force of the weight is increased, the output voltage increases linearly and vice versa. The output is an analog value, which makes it simple to interface to microprocessor.

In order to detect, we have developed an algorithm to acquire data from the sensor through PCI- 9111 DG using a BC++ program to find an occupant or an empty passenger seat. Once the detection is made, classification decision as to whether the occupant is an adult, child or non-human object is done based on dynamic weight measurement techniques. After the occupant has been classified, the position of the occupant is determined by calculating the centroid distance from the center of the seat in the x and y directions. This is assumed to be positioned at the intersection of the seat to left, right, front and back.

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1. Experimental Setup

In this work, the application of weight sensing for the prototype implementation of a novel intelligent system for occupant classification and position detection is considered. MEMS sensor and its technology is used along with a PCI-DG 9111 card for data acquisition. ACLD 9137 connector is connected between the analog output of sensor and the acquisition card. An interface algorithm is developed with Borland C++ program for the sensor output and PCI card.

The proposed sensing system prototype is implemented and its performance is analyzed. To illustrate the performance, some exemplary results obtained from the prototype system are demonstrated. The illustration shows the detection for instances such as, when the seat is occupied or empty, and if occupied the occupant is classified as an adult, child or non-human object. It also demonstrates that the position of the occupant can be determined for consideration of safety issues in airbag application or for measuring the comfort level. Classification of human and non-human object in the car seat is an important issue. Usually, human in the seat provides its weight with positional variation. However, non-human object like grocery bag is static and provides its weight without positional variation. In our interface algorithm, occupants total weight equals '0' is classified as non occupancy, 0.1 to 10 without positional variation as non-human object, 10.1 to 35 and above 35 with positional variation as child and adult, respectively.

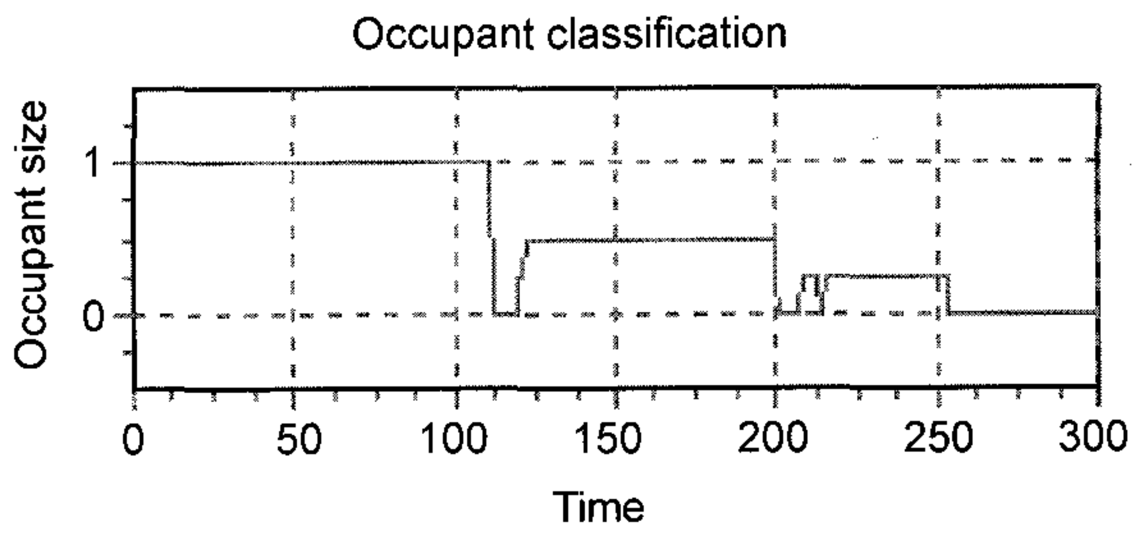

Figure 5. Occupant classification.

4.2. Results and Discussions

In the interface algorithm, we have set the identification (id) of adult, child, non-human object and empty as '1', '0.5', '0.25' and '0', respectively. Next, we perform the categorization task by introducing the conditions of adult, child, non-human object and no occupancies. Results are shown in Figure 5 which correctly depicts the chronological sequence of testing. Therefore, it can be concluded that the developed prototype is robust for occupant classification.

Figure 6 indicates the class of occupant and its four sensor data. The sensor and its circuitry provides accurate data, which is extremely useful in our robust prototype implementation. In the experiments for the adult case, it

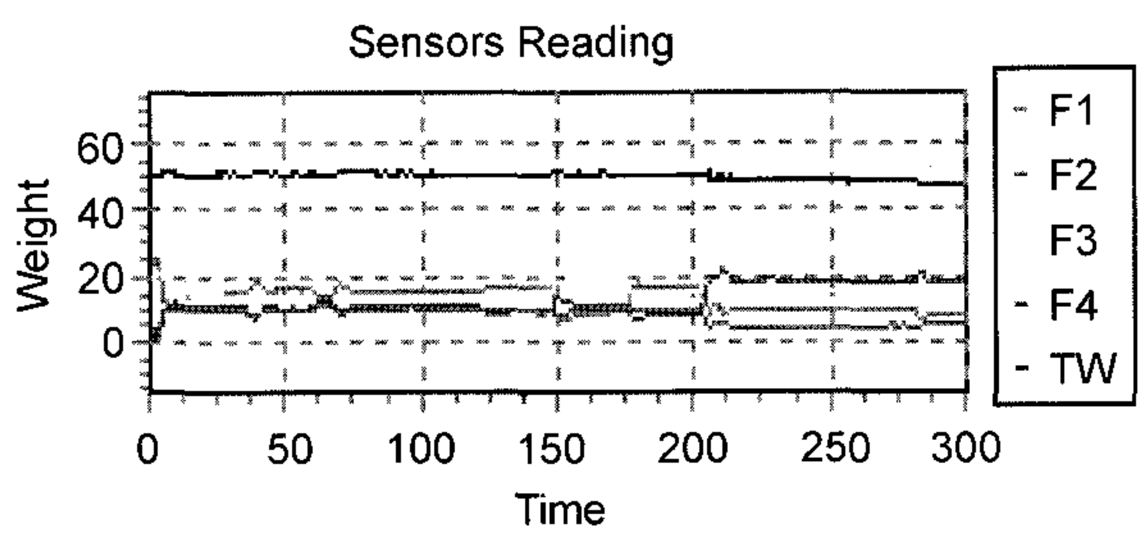

Figure 6. Sensor individual and total weight readings.

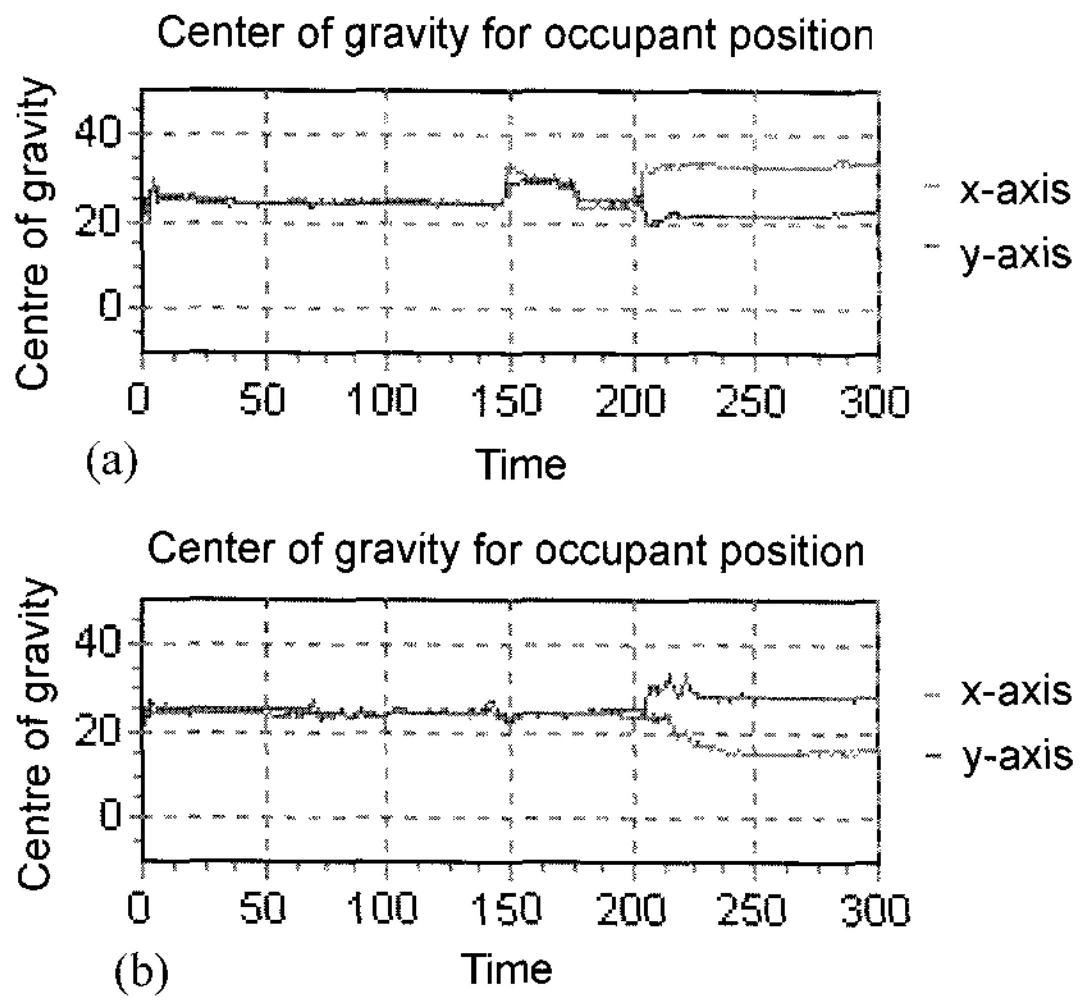

Figure 7. Centre of gravity for occupant position.

can be seen from Figure 6 that the total weight of the occupant is greater than 50 kg while the output responses of individual weight sensors range between 10 to 20 kg for up to 200 sec, with no significant differences between them. These results show that the occupant is an adult and the position is perfect and safe. However, after 200 sec, the individual sensors weights start to vary, which implies that the occupant is somewhat align to one side and this indicates that the occupant is not in a safe position and the airbag should not deploy.

Figure 7 also shows the position of the occupant, whether it is perfect or not. The centroidal distances of x and y directions have been plotted independent of the occupant significant position. In Figure 7(a), at time equals ~200 s the resonant peaks in the *x* direction (red) show higher positive values than the y direction (green), which means that the occupant torso is slanting to the far right. On the contrary, Figure 7(b) shows the peak values of x direction (red) at time ~200 sec to be lower than the values of y direction (green), which means that the occupant's upper body is now slanting left and towards the front of the vehicle. When the two values differ, it reflects an unsafe occupant postion and therefore, it can be concluded that both conditions (at time after 200s) are unsafe. This should trigger an alert to warn the occupant. Based on these results, it is reasonable to conclude that our approach to monitor unsafe occupant position is robust and effective.

5. CONCLUSION

This paper has described the prototype implementation of an intelligent, robust and safe airbag system that uses weight sensing technology to detect and monitor occupant's position. The system is developed with the aim to ensure front seated passenger safety. The key success of this system is on its bonafide detection, classification and position calculation techniques that are unique. Outcome of this research may be used in the intelligent airbag design for efficient deployment.

ACKNOWLEDGEMENT–The authors would like to acknowledge Vong Li Li and Lee Hong Fah for their assistance in the system design. The authors also would like to thank the Malaysian Ministry of Science, Technology and Innovation for funding this work through research grant IRPA: 03-02-02-0017-SR0003/07-03.

REFERENCES

AAP (American Academy of Pediatrics). (2006). Car safety seats: A guide for families. (Online) http://www.aap.org/family/carseatguide.htm (11 January 2006).

Bob, B. (2005). The torsional sensing load cell for occupant positioning sensing. (Online) http://www.gagetek.com/autocell.pdf (15 April 2005).

Devy, M., Giralt, A. and Marin-Hernandez, A. (2000). Detection and classification of passenger occupancy using stereovision. *Proc. IEEE Intelligent Vehicles Symposium*, Dearborn (MI), USA, 714–719.

Gautama, S., Lacorix, S. and Devy, M. (1999). Evaluation of stereo matching algorithms for occupant detection. *Proc. Int. Workshop on Recognition, Analysis, and Tracking of Faces and Gestures in Real-Time Systems*, 177–184.

John, D. (2000). Out of harm's way. Mechanical engineering. (Online) http://www.memagazine.org/backissues/dec00/features/feat_toc.html (15 October, 2005).

Jeff, K. and Candace, S. (2005). Auto sensors play small role in reducing child airbag deaths. (Online) http://stm.pennnet.com/articles/article_display.cfm?article_id=267590 (27 March 2005).

Klomark, M. (2000). *Occupant Detection Using Computer Vision*. M. S. Thesis, Computer Vision, Linköping University.

Krotosky, S. J., Cheng, S.Y. and Trivedi, M. M. (2004). Face detection and head tracking using stereo and thermal infrared cameras for "smart" airbags: A comparative analysis. *Proc. 7th Int. IEEE Conf. Intelligent Transportation Systems*, 17–22.

Microfused Silicon Strain Gage (MSG), Hermetic Pressure Sensing. (2005). (Online) http://www.ti.com/snc/products/sensors/auto-msg.htm (21 March 2005).

NuDAQ, PCI-9111DG/HR. 2000. Multi-Functions Data Acquisition Card User's Guide. (2003). (Online) http://www.ciclope.info/display/docs/manual.PCI9111.pdf (23 July 2003).

NSC (National Safety Council). (2005). Crisis to progress:

Airbag safety five year report. (Online) http://www.nsc.org/library/cristext.htm (28 April 2005).
Owechko, Y., Srinivasa, N., Medasani, S. and Boscolo, R. (2003). High performance sensor fusion architecture for vision-based occupant detection. *Proc. IEEE Int. Conf. Intelligent Transportation Systems,* **2**, 1128–1133.
Shigeyuki, N. (2004). Development of occupant classification system for advanced airbag requirements. *Mitsubishi Motors Technical Review,* **16**, 61–64.
Stephen, L. (2005). New child car seat regulation. (Online) http://www.chop.edu/consumer/jsp/division/generic.jsp?id=77979 (26 December 2005).
Timothy, D. S. and Trivedi, M. M. (2003). Real-time stereo-based vehicle occupant posture determination for intelligent airbag deployment. *Proc. IEEE Int. Conf. Intelligent Vehicles,* 570–574.