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High Resolution Pressure Sensor Distributed Floor for Future Human-Robot Symbiosis Environments

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Abstract

This paper proposes a high resolution sensor floor which can detect both humans and robots simultaneously. Each sensor floor unit is 500mm square and is equipped with 4,096 pressure switches distributed in a 64 ×64 array. A 2m by 2m sensor floor with 16 of these sensor floor units has been realized. Experiments with this sensor floor have determined successfully the positions of a human and a 4-wheeled cart and can distinguish between them. The distinction is easily achieved because of the high resolution of the floor. The modular structure of the sensor floor enables easy application to a real room of irregular shape, allowing unconstrained measurement of the locations of humans, robots and objects in the room. Consequently, sensor floor systems will be essential components of future human-robot symbiosis systems to assist humans in daily life, and will also play important roles in medical and welfare robot systems.

1 Introduction

The development of humanoids and welfare robots is attracting keen attention among robot engineers and researchers. In the near future, a human-robot symbiosis environment, where robots assist humans in ordinary houses, may become feasible. Within this stream of technology, the authors have been developing a Robotic Room[1], where the room itself is a robot system that offers assistance to the humans living in it. A key requirement of such applications is the ability to simultaneously measure accurately the positions of humans and robots in the room. While a number of attempts to do so employ robot-mounted vision systems or distributed vision sensors in the room, vision sensors are sensitive to changes in lighting conditions and are prone to occlusion of the target object. These problems frustrate the realization of robust vision systems.
To realize robust and occulsion free detection of humans and robots, we deployed a switch array in the floor, since humans and robots almost always transmit their weight to the floor when they are in a room. Techniques for measuring pressure distributions with a sensor array have been studied by Ishikawa et al and they succeeded in realizing a tactile sensor for imaging the pressure distribution of a hand in contact with the sensor[2]. Nitta Corporation[3] is selling several kinds of pressure distribution measurement sensor systems for automobile design and human behavior measurement. However, all of these solutions are for the measurement of the pressure distribution in a limited area, and they are not intended to measure the overall pressure distribution in a room.

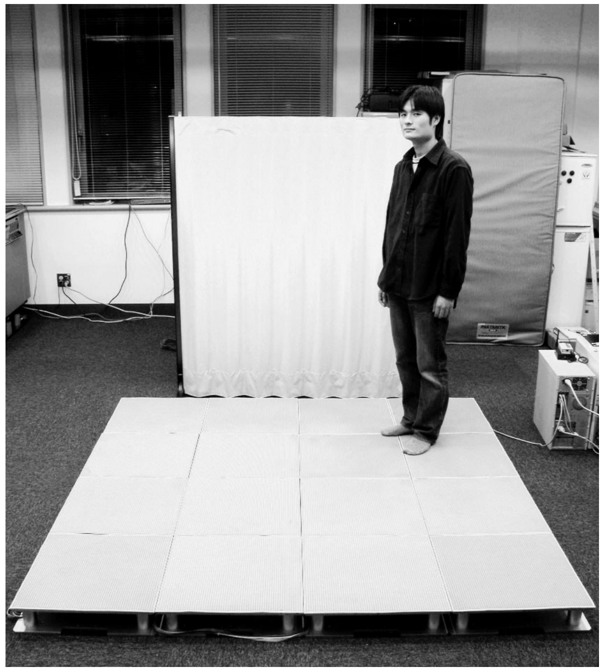


Figure 1: *Pressure Sensor Distributed Floor Made with 16 Sensor Floor Units*

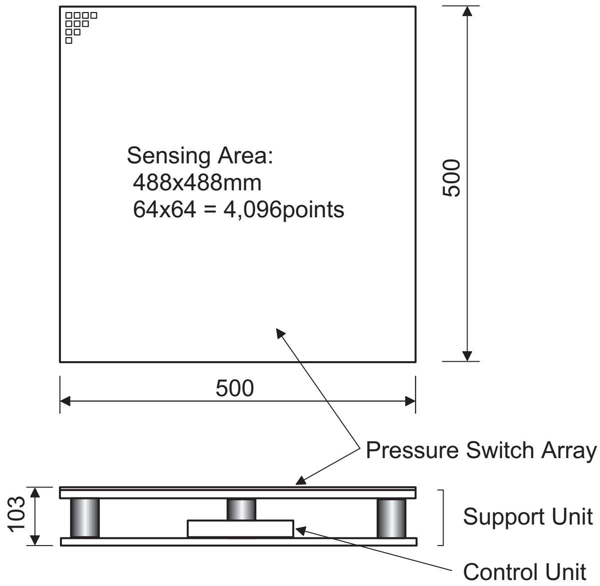


Figure 2: *Structure of Sensor Floor Unit*

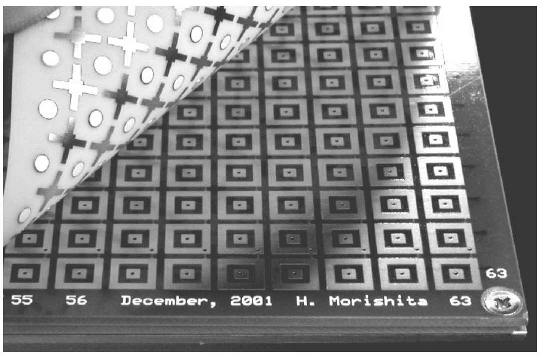


Figure 3: *Cover and Base PCB of Sensor Floor Unit*

2 Structure of Sensor Floor Unit

Figure 1 shows a Distributed Pressure Sensor Floor made of 16 sensor floor units arranged in 4×4 array. The structure of the sensor floor unit is shown in Figure 2. The sensor floor unit consists of three parts: 1) a pressure switch PCB (Printed Circuit Board) which detects the pressure distribution, 2) a support unit to hold the switch PCB, and 3) a control unit to control the switch PCB, process the data and transmit it to the serial data bus.

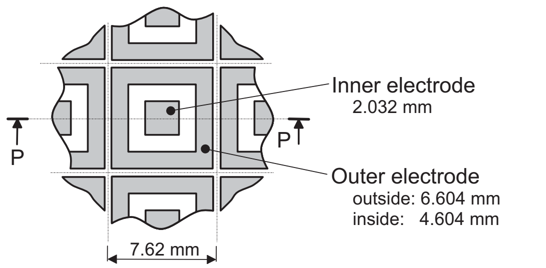
The key requirement for the reliable sensing of such a switch array using row and column lines is the elimination of electrical interference from the sensing points. Snyder[4] put a diode at each point to reduce noise, and Pubrick used the voltage mirror method[5]. Ishikawa directly switched the nodes using an FET installed at each point. The authors have adopted Snyder's technique of putting diodes at each sensing point, as this solution enables low cost, large scale and high speed measurement.

The signals from the pressure switch PCB are routed to two 64pin connectors on the backside of the board and are connected to the control unit through connection holes on the top board of the support unit. This sensor floor unit has the same external dimensions as the free access floor units widely used in an offices, which makes it easy to install them in a room of any shape.

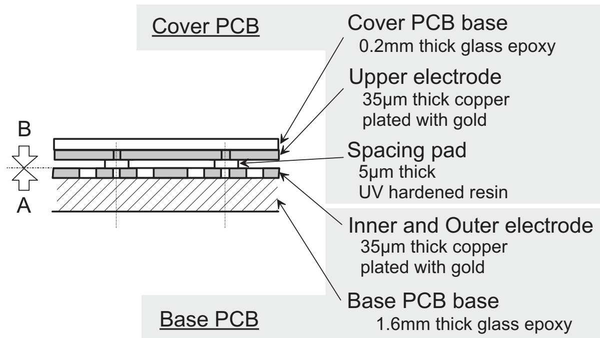
In the design of the sensor floor unit, special care was taken to realize the following features. 1) The sensor PCB is designed so that the edge margin, where no sensors can be fabricated, is as small as possible. 2) The surface mount type diodes are placed on the backside of the base PCB to avoid the creation of non-sensing area on the top surface. 3) The sensor PCB and its control circuit PCB are designed separately, so that the control circuit alone can be replaced when a faster one becomes available. 4) Sensor floor units can be connected together on any edge and the control line can be BUS-connected so that the number of the units can be increased to accommodate any room.

2.1 Pressure Detection PCB

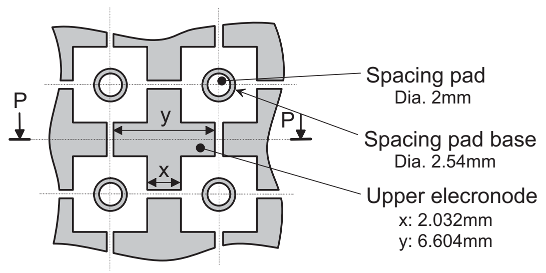
An overview of the Pressure Detection PCB is shown in Figure 3. It consists of two parts, 1) a cover PCB and 2) a base PCB. The cover PCB is put on the base PCB which is screwed to the support unit. Figure 4 shows the structure of the pressure switch PCB. The dimension of the base PCB is $498mm \times 498mm$. On its top surface, 4,096, 6.032mm, double square pads have been fabricated in a 64×64 array. Cruciform pads have been etched on the cover PCB at positions corresponding to the double square pads on the base PCB, as shown in Figure 4. Spacing pads made of UV hardened resin are located at the center of the four cruciform pads. These spacing pads keep the contacts separated when there is no pressure on the cover PCB, ensuring that the inner and the outer square electrodes of the double square pads are electrically disconnected. When pressure is applied on the thin cover PCB surface, it deforms easily (Figure 5) and the cruciform pads contact the double square pads on the base PCB to close the circuit of inner and outer electrodes. All the pads on the cover PCB and the base PCB are plated with gold for better electrical contact, reliability and durability.



(a) B view: Surface side of Base PCB



(b) P-P cross section



(c) A view: Back side of Cover PCB

Figure 4: *Sensor Structure in Detail*

2.2 Support unit

The support unit has a hollow structure in which the 498mm square top plate and the 500mm square bottom plate are connected with 5 pillars. The total height of the support unit is 100mm, the same as a standard 100mm free access floor unit. On the top plate, there is a 1.6mm thick spacing plate with 4,096 holes to protect the diodes on the backside of the base PCB. Two oblong holes are made on the top plate and the spacing plate for the connecting cable from the base PCB to the controller. There are four screw holes in the bottom plate for the leveling feet.

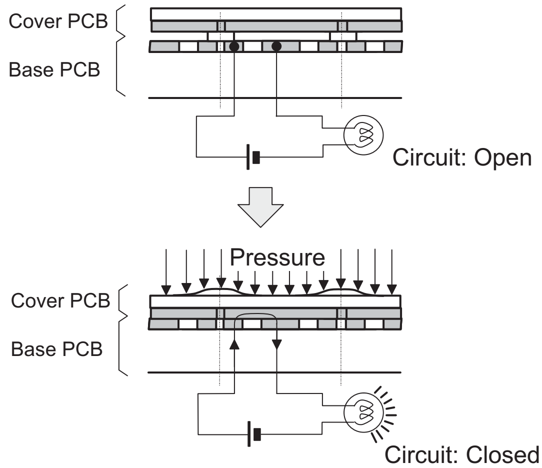


Figure 5: *Operation of the Sensing Pads*

2.3 Control circuit

Figure 6 shows the structure of the control unit. The inner electrodes of the pads in each row are connected to a common conductor through diodes to avoid interference, and the conductor is connected to a designated pin on the 64-pin ROW connector on the backside of the base PCB. The 4,096 diodes, one for each double square pad, are surface-mounted on the backside of the base PCB. The outer electrodes of the pads in each column are wired together and connected to the corresponding pin on the 64-pin COLUMN connector on the backside of the base PCB. The controller consists of an embedded type microcontroller, 64 bits open collector line decoder, 64 to 8 demultiplexer and other peripherals. During measurement, one column line is selected by the line decoder, and then the row is read with 8 bits at once. Since the input lines of the demultiplexer are pulled up to the logic high level through registers, the points with no pressure are read as a logical high level and the points with pressure are read as a logical low level.

Each sensor unit has a unique ID number for access from the serial bus where the data is transferred at 115.2k bps. In addition to the most basic transfer mode, which transmits the 4,096 ON/OFF signals as 512 byte packets, the controller has several other data transfer features, such as: 1) ON/OFF patterns are sent in a 1/0 character stream, which is normally used for maintenance of the sensor. 2) Sensing area can be selected with an 8×8 area as a unit. 3) Measured data can be sent in a compressed format.

The latter two features can contribute significantly

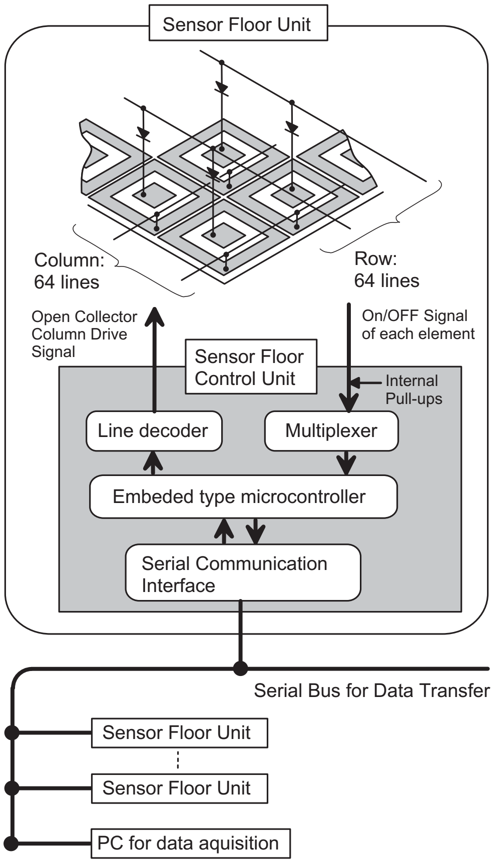


Figure 6: *Structure of the Sensor Floor Unit Controller*

Table 1: *Approximate Pressure Caused by A Human on A Floor*

Condition	Pressure, kPa
1. Standing on both feet	26
2. Standing on single foot	52
3. Standing on both toes	120
4. Standing on sigle toe	240

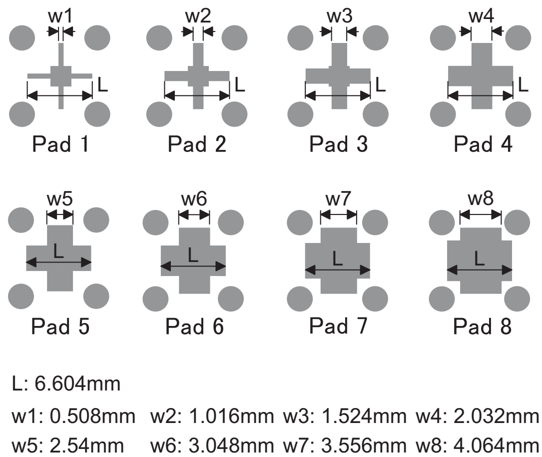


Figure 7: *Shapes of Pads Tested for Optimization*

to the efficient use of data transfer line bandwidth. In the case of compressed mode transfer, the number of bytes transferred for unit measurement differs with the bit pattern obtained. In the case where all the points are ON or OFF, a minimum of 6 bytes of data are transferred. This is quite efficient when we apply the sensor floor in a normal room, because the fraction of the area where a human or a robot is located is small and the other area in the room is empty.

3 Influence of the shape of the upper electrode on transition pressure

This sensor floor was developed to locate the position of a human or robot on it. The pressure produced when a human stands on the floor is shown in Table 1. These values were obtained by dividing the weight of one of the authors by the area contacted on the floor.

To design a sensor floor, it is important to determine the threshold pressure at which the switch turns ON. When the pressure is too large, which means that the sensitivity of the sensor is too low, the sensor floor cannot detect light objects. Thus, the authors set the threshold pressure slightly lower than the the values in the Table 1. In the case of robots, it is difficult to estimate the pressure, since the configuration and weight may be quite different, depending on the design of the robot. However, in general, the pressure will be at the same level or higher than it is in the case of a human.

In the case of the sensor floor, the applied pressure is converted to deformation of the cover PCB. Therefore, the threshold pressure is determined by the material of the cover PCB and by the dimensions of the copper patterns on it. Through preliminary experiments, the authors selected FR4 (Glass- epoxy) of 0.2mm thickness for the PCB, and investigated the change of threshold pressure with changing electrode patterns. The eight patterns shown in Figure 7 were prepared. The thickness of the copper cladding was 35μm, with 3μm nickel and 30nm gold overplatings. 5μm thick spacing pads of UV hardened resin were prepared on the round lands at the corners.

The threshold pressure to switch from OFF to ON was investigated using 8 small size cover PCBs with

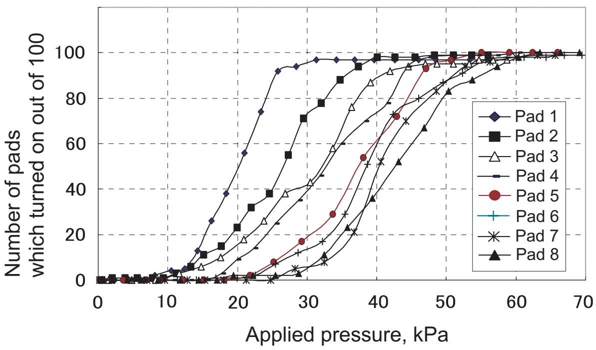


Figure 8: *Difference of ON Pressure according to the Difference of Pad Shape*

512 each of the 8 types of pads mentioned above. The 8 test cover PCBs were layered onto the base PCB, and isotropic air pressure was applied. The number of points which turned ON was recorded with increase in applied pressure. To eliminate edge effects, the measurement was done only with the $10 \times 10 = 100$ points at the center of the test PCBs. The result is shown in Figure 8. Because the cover PCB has a two layer structure with FR4 and copper patterns laminated, it was expected that the threshold pressure would increase along with the increase of the area of copper. The result shows the expected inclination. By comparing the results in Figure 8 with the values in Table 1, the Pad 1 and 2 were determined to be appropriate for detecting humans. The authors adopted Pad 2 in the experimental setup shown in Figure 1, taking the durability of the contacts into consideration.

4 Experiment

Figure 9, Figure 10, and Figure 11 show the experimental results for a human walking barefoot, a human walking in shoes, and a 4-wheel cart, respectively. These data were obtained by accumulating sensor images over time. A single data reading has, in case of Figure 11 for a 4- wheel cart, just four marked areas at the points where the four wheels contact the floor. The registration dots at regular intervals in the figures were added at a spacing of 10 sensing pads, corresponding to 76.2mm.

Comparison of Figure 9 and Figure 10 shows a sharp distinction between the images produced by bare feet and with shoes, and there's a good possibility that this could be automatically distinguished by image processing software. Moreover, in the case of bare feet, the footprint image and walking characteristics obtained by the sensor floor may be useful in personal identification.

The 4-wheel cart experiment, shown in Figure 11,

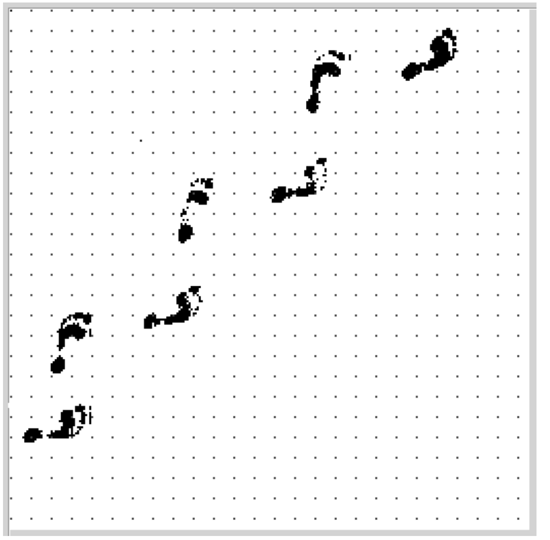


Figure 9: *Images Obtained when Walking on Bare Foot*

was executed to investigate the possibility of detecting a mobile robot with wheels. The pattern is clearly different from the images in Figure 9 and Figure 10, which means that it is easy to distinguish human and mobile robots. In addition, the position and the orientation of the mobile robot on the sensor floor could be extracted very accurately and robustly.

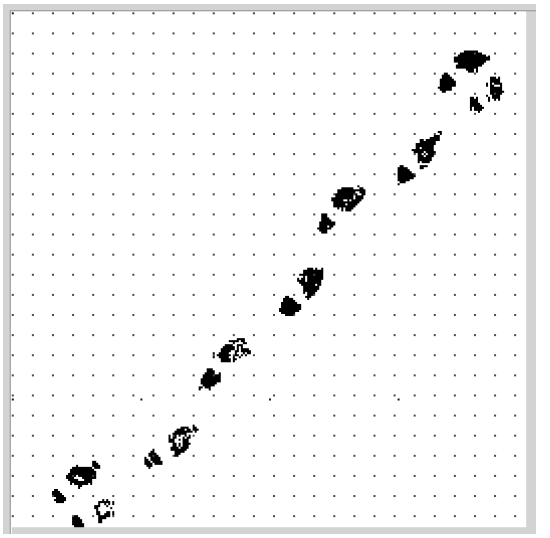


Figure 10: *Images Obtained when Walking with Shoes On*

5 Discussion

The current control unit uses a conventional serial communication method for data transfer, and is the

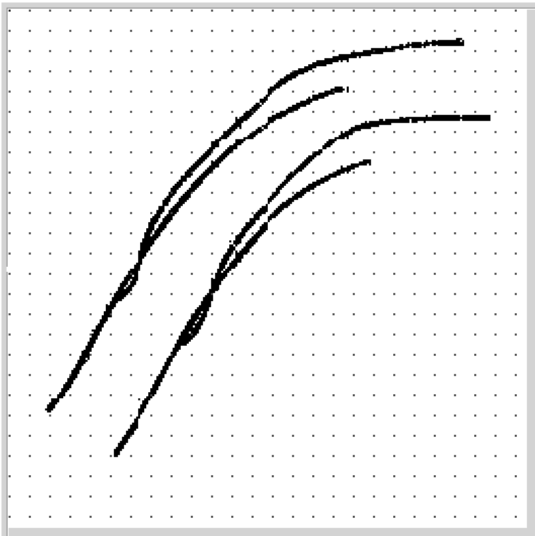


Figure 11: Images Obtained when A 4-wheel Cart Is Moving

bottleneck for increased sampling rate. For a sensor floor with 16 units, the sampling rate is limited to about 15Hz, and will be improved significantly by introducing communication through USB or Ethernet. The sensor floor discussed in this paper gives only an ON/OFF signal for each sensed point, but the sensor PCB and the control circuit were designed so that they can also measure the pressure as an analog value by incorporating a pressure sensitive conductive rubber between the cover and the base PCB. Through this improvement, it will be possible to estimate the total weight of the object on the floor and to find the center-of-gravity of the pressure distribution.

6 Conclusion

The authors developed a $2m \times 2m$ high resolution, distributed pressure sensor floor element with 65,536 pressure switches, and evaluated its performance in experiments sensing a human and a 4-wheel cart.
The features of the sensor floor system can be summarized as follows:

- High spatial resolution of 7mm was achieved.
- The spatial resolution remains the same even when the sensing area is expanded by increasing the number of sensor units, while the resolution of a vision sensor system decreases according to the distance from the object.
- There is no distortion in the obtained image, compared with a vision sensor, for which the distortion of the data differs with the distance to the object.
- As this system is measuring the pressure on the floor, the system can detect the object as long as it is on the floor, while a vision sensor system sometimes loses objects due to occlusion.
- Positions of multiple humans and robots on the floor can be measured simultaneously and they are easily distinguished from each other by the obtained pressure pattern.
- The sensor floor can be extended in 500mm square units and can fit most existing rooms.

The authors are convinced that this sensor floor can be used to understand the behavior of humans in a room, and that it will also play an essential role in the future human-robot symbiosis environment by detecting the position and direction of humans and robots in the room.

Acknowledgments

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