A High Resolution Tactile Sensor

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A high-resolution tactile sensor using pressure-optical conversion technique was developed. The sensor system consists of a transparent acryle plate, an elastic sheet, a light-guide made of plastic fibers and a 32x16 phototransistor array. The elastic sheet, the surface of which is sensing surface, is placed on the acryle plate(56mm x 117mm). The light guided via a light-guide was incident upon one end of the plate. The light conducts in the plate by total internal reflection if no pressure is applied on the elastic sheet. Pressure applied onto the sheet causes an optically active contact between the sheet and the plate whereby the total internal reflection conditions are changed and the light illuminates the sheet. The sheet scatters the light back in the area of the pressure and the patterns of the pressure area can be observed by a phototransistor array. The output of array was transferred to the computer serially for tactile image processing. The evaluation experiment showed the system to work well.

1. INTRODUCTION

High resolution tactile sensors provide a lot of benefits for robot arms to perform tasks dexteriously. Firstly, this type of sensor is useful for a robot to stably grasp an object because it enables a robot to precisely identify the location and orientation of an object which is held in a gripper. Secondarily, it can be effectively used to recognize a profile of an object with complicated surface in the environment where visual sensors can not work well because visibility is poor.

There are several researchers concerned with the development on high resolution tactile sensors[1]-[9]. Simple high resolution tactile sensor is consisted of array of contact like limit switches and produces only contact pattern information via on-off signal pattern [1]. In order to get pressure pattern information , a conductive rubber or a sponge including powdered carbon is most popular material used for constructing the sensors[2]-[7]. The principle of tactile sensing in this type of sensor relates to measuring resistor change caused by the deflection of elastic membrane when it contacts a rigid object. This type of sensor system will give enough information, compared with simple contact array tactile sensors, but the resistive readout sensor requires some cautions to manufacture the array construction with high density.

There are many small size opto-electronic devices. If the pressure information, therefore, is converted to optical information, it may become easy to construct high resolution sensor relevant to detect pressure distribution[8].

This paper proposes a tactile sensor of robot hands using pressure-optical conversion technique with detection ability of complex tactile patterns. The basic principle proposed in this paper has been used for displaying the distribution of pressure in the soles of the foot or measuring the center of gravity of human body during human walking from the displayed pressure distribution in rehabilitation engineering field. This kind of device is widely known as the pedobarograph [10][11] and is one of excellent high resolution imaging touch sensor systems. However, pedobarograph is usually too big to be a tactile sensor installed in a robot system.

The objective of this paper is to develop high resolution tactile sensor system suitable for robot hands by use of the principle adopted in pedobarographs.

2. SENSOR SYSTEM

A sensor system developed includes a transparent acryle plate, an elastic sheet, a light-guide made of plastic fibers, a light source and phototransister array. Fig. 1 shows the general lay-out of the sensor system. An acryle plate is put on a phototransistor array. An elastic sheet is placed between the acryle surface and an object. The elastic sheet has irregular surface at one side which contacts with the acryle surface.

The function of the sensor system is based on the conduction of light by total internal reflexion in a transparent material, acryle plate and the use of an elastic foil as a means of transfer of pressure to the light conducting surface. If no pressure is applied on the elastic sheet, the surface of the sheet is not in optically active contact with the light conducting material and viewing field observed from the free (phototransistor array) side is dark. Pressure applied onto the sheet causes an optically active contact between the sheet and light conducting material whereby the total internal reflexion conditions are changed and the light illuminates the sheet. The sheet scatters the light back in the area of the pressure and the patterns of the pressure area can be detected by the use of optical-electrical signal conversion devices, phototransistor array.

Irregular surface of the sheet will cause an increase of contact area to the acryle plate surface according to an increase of applied pressure. This results in increasing intensity of scattering light observed by an optical sensor. Therefore, the sensor system can measure not only the patterns of pressure area, but also normal force distribution in the sensitive surface via intensity of the light which illuminates the sheet.

3. DESIGN OF SENSOR SYSTEM

3.1 Plate

An optical medium suitable for the conduction of the light by total internal reflection has to be transparent for the light used, optically homogenious, refractive, suitably shaped and of necessary strength. Acryle was chosen as a material which satisfies above conditions. The size was 117mm(length)x56mm(width)x10mm(thickness), which was decided under the consideration of a size of the gripper in which the system will be installed.

Fig. 2 shows the experimental result of optical transparency of acryle plate. To obtain this result, several length plates were prepared. The optical fiber guided light was projected from one side of each length plate and the intensity of light conducted through the plate was measured by a phototransistor placed at the other facing side. Surfaces of each plate except the side where the light was projected and the side where a phototransistor was placed were silver vacuum vapour coated to get the uniform reflexion in the plate. From the observation of the result, it can be found that the acryle plate is favarable in optical characteristics for this sensor system.

The plate used in the developed sensor system is shown in Fig. 3. Each surface was silver vaccum vapour coated except surfaces where an elastic sheet and a transistor array were attached. At the side where the light was projected, the surface was silver vacuum vapour coated except the area with which the light guide fiber contacted directly.

3.2 Light Source and Light Guide

An intensity adjustable halogen lamp was adopted for light source. The light source used was too large to be attached to the sensor directly. Therefore, a plastic optical fiber guided the light to the plate from the light source which was placed away from the sensor. Fig. 4 shows light source and light guide. As shown in the figure, the optical fiber has linear cross section at the end contacted with the plate, which enables the projection of flat beam to the plate. This configuration of optical fiber is effective to obtain good condition for total internal reflection in the plate. The selection of the projection angle of flat beam to the plate is important for favarable total internal reflexion. In this case, the flat beam was projected at the right angle on the surface of the proper side of the plate.

3.3 Elastic Sheet

The elastic sheet has to be capable of reflecting back light which comes out from the plate, and light-coloured materials are therefore suitable. In the developed sensor system, a white silicon rubber sheet was used.

The surface structure of the elastic sheet determines the resolution of the reflecting pattern. The irregular structure needs to be fine enough to present a continuous reflecting pattern to the phtotransistor array. With the problem in mind, a conic irregular surface structure were employed. The cross section is shown in Fig. 5. The pitch of the irregular pattern is approximatly 1 mm and the vertical angle of the cone is 118 degrees. The maximum thickness of the sheet is about 2mm. Fig. 6 shows an example of the reflecting pattern occurred when the sheet was pressed by the fingers.

3.4 Phototransistor Array and Electronic Circuits

The phototransistor array structure has to be carefully designed because it determines the resolution of the sensor. In order to get high-resolution sensor system, miniature phototransistors should be chosen for an element of the array. From the investigation of phototransistors commercially available, TPS 6Ø3 phototransistors were selected, each of which has 3mm diameter circular sensitive surface. They were put in holes which were arranged on a base plate made of a plastic material at intervals of about 3.5mm and it allowed constructing a 16 x 32 sensor matrix on a sensitive area of the plate. The Fig. 7(a) shows the phototransistor array manufactured.

In the development of a high resolution sensor system, one of the most important problem to be solved is how signal lines should be drawn. It is unfavarable to get the output signal from each phototransistor independently because it requires complex wiring and networks. To reduce the number of necessary connection, a scan circuit of the array was designed. Fig. 7(b) shows the schematic diagram of the circuit. The array was scanned by applying a voltage to one column at a time. In Fig. 7(b), each column is connected to a fixed voltage source(1Ø V) through a switching transistor which is included in a TTL inverter with open collector output. If the decorder selects one column, the switching transistor attaching to the column will be open and a fixed voltage is placed on the column, while all other columns are held at ground potential by closing switching transistors attaching to those columns. The output of each element in the selected column was multiplexed and was sent to a computer(PDP 11/44) after AD conversion. The selection of a column and the switching of multiplexer were performed by a computer software.

4. EVALUATION EXPERIMENT

The experiment setup used is shown in Fig. 8. Before experiments, calibration process for each phototransistor was performed. In order to achieve the calibration, the sensitive area of the sensor system was pressed uniformly with several pressures and the relation between the applied pressure and the electrical output for each phototransistor was measured. Each relation was approximated using a linear function described by two parameters and was used for later data processing. An example of calibration function is shown in Fig. 9. The vertical axis is indicating the illuminance instead of the direct output of phototransistor for convenience and is normalized by the illuminance for 1kg/cm^2 pressure. From the figure, it is found to be valid to describe the relation using a linear function.

Several evaluation experiment were conducted with varying applied pressure and elasticity of silicon rubber. A hemispherical object with a diameter of 35 mm was used as an object, the profile of which was measured. A sample image of the top of the object is shown in Fig. 1Ø. This was obtained by putting a 4.2 kg weight on a sensitive surface of the sensor system via the hemispherical object. The vertical axis is normalized by the maximum pressure value. Cross points of the mesh in the bottom surface correspond to the locations of each phototransistor. Dotted lines indicate the equal contour pressure curves. From the result, it is found that the developed sensor system gives information necessary to recognize a three-dimensional profile of the object.

5. CONCLUSIONS

In this paper a tactile sensor system using a pressure-optical conversion technique was discussed. Some basic evaluation experiments were conducted and showed the sensor system worked well. In the proposed system, a phototransistor array was used for a pressure-optical conversion device, in which the size of each phototransistor determined the resolution of sensor. If a smaller pressure-optical conversion element can be employed, the resolution will be improved. Solid state image sensors like CCD or CID device are attractive for this purpose. In the present stage, however, these devices are too small to be closely attached to the transparent plate which was used in the proposed system. In future, the appearance of a contact type solid state image sensor may contribute to the improvement of the resolution of the sensor system.

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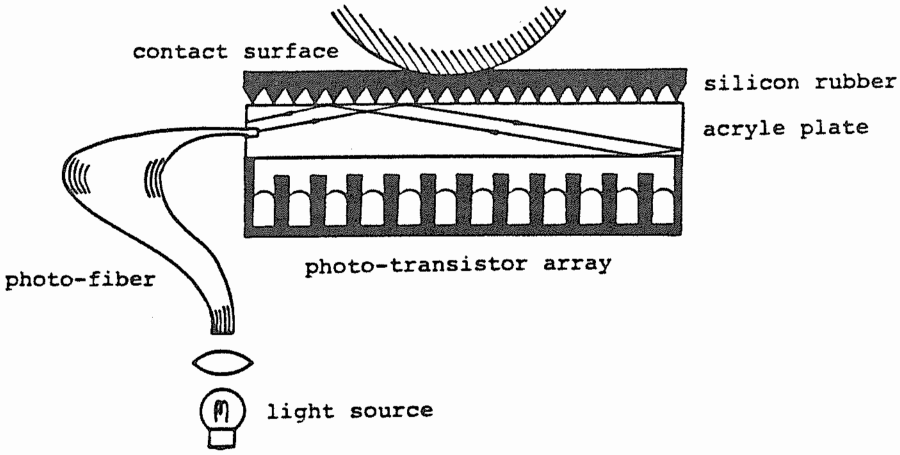


Fig. 1 General Lay-out of the Sensor System

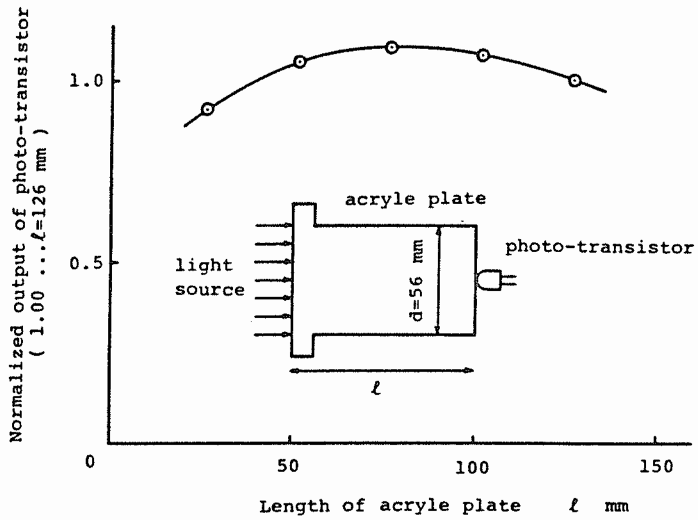


Fig. 2 Experimental Results of Optical Transparency of the Acryle Plate

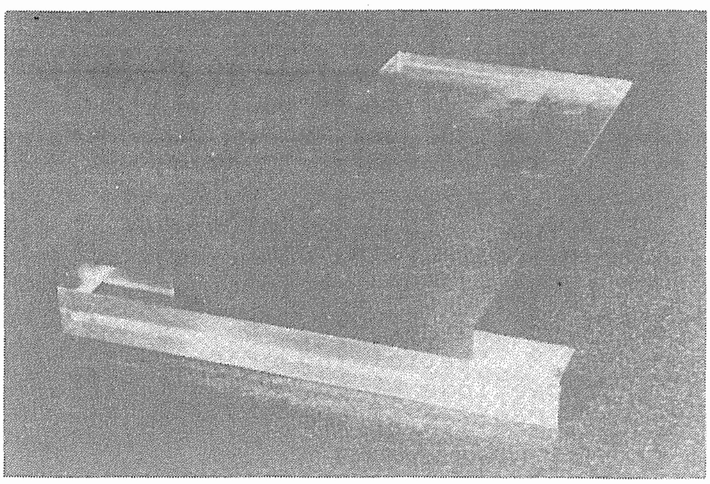


Fig. 3 Plate Used in the Developed Sensor System

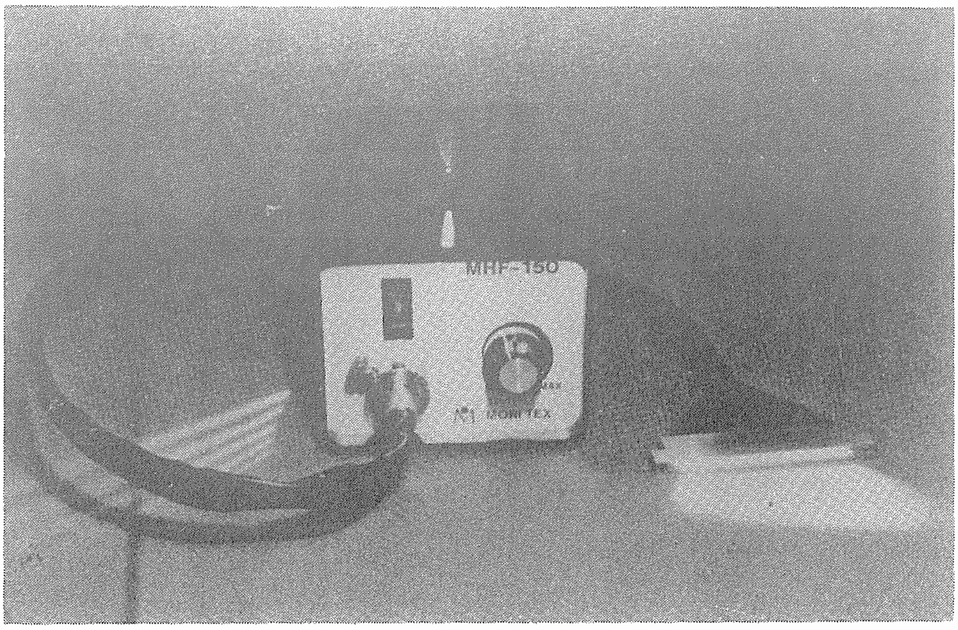


Fig. 4 Light Source and Light Guide

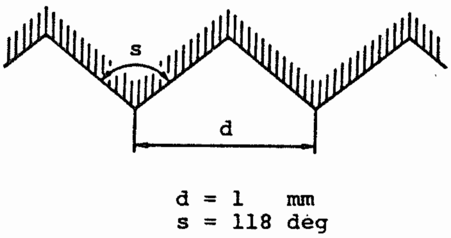


Fig. 5 Cross Section of the Elastic Sheet

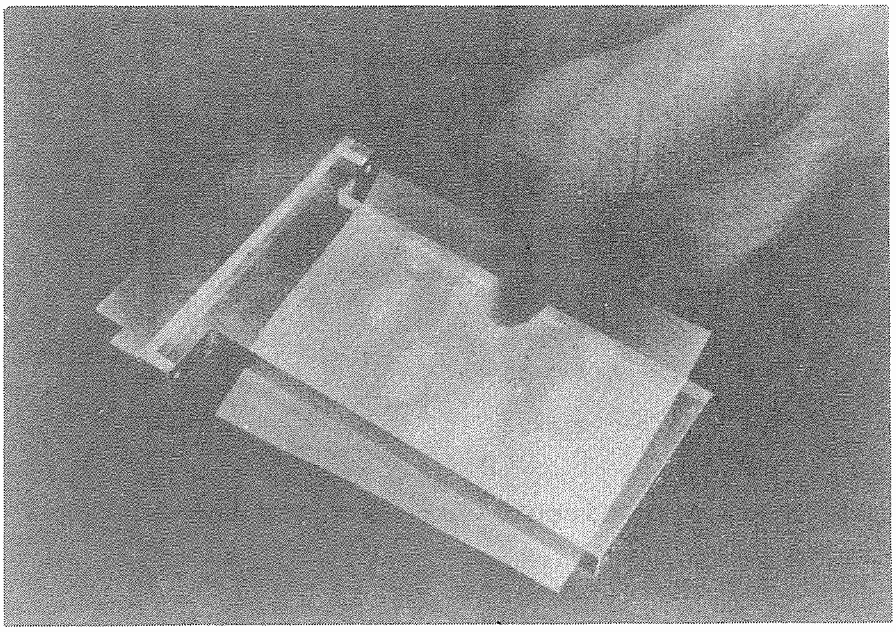
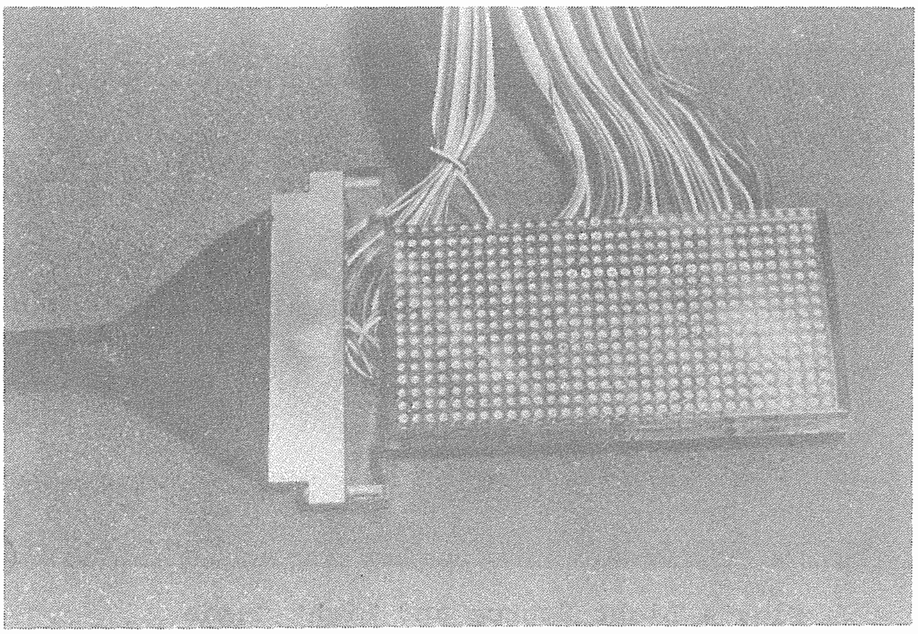
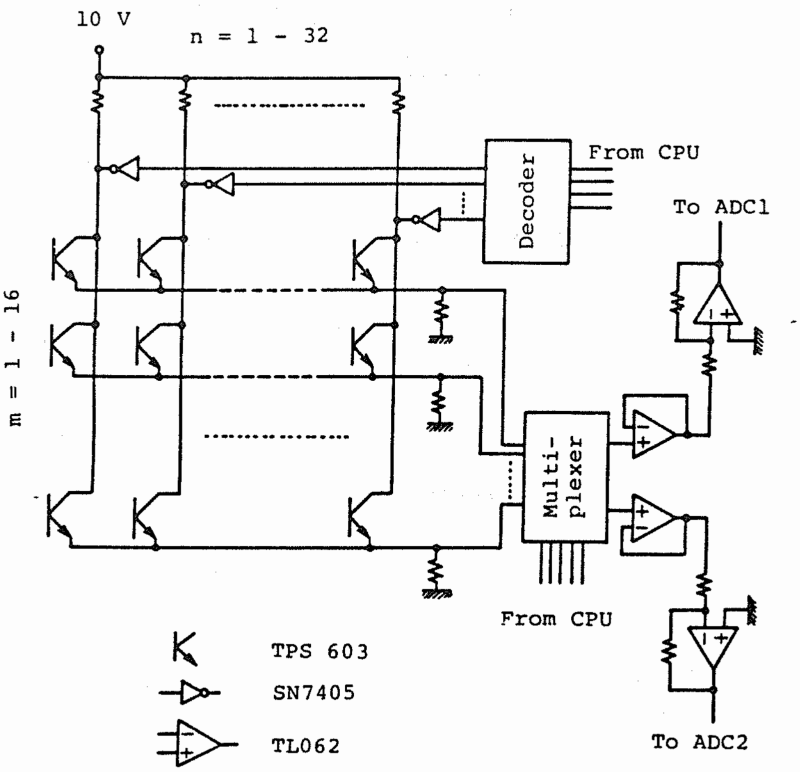


Fig. 6 An Example of Reflecting Pattern



(a) Phototransistor Array Attached with the Acryle Plate



(b) Electronic Circuit for Scanning the Array

Fig.7 Phototransister Array

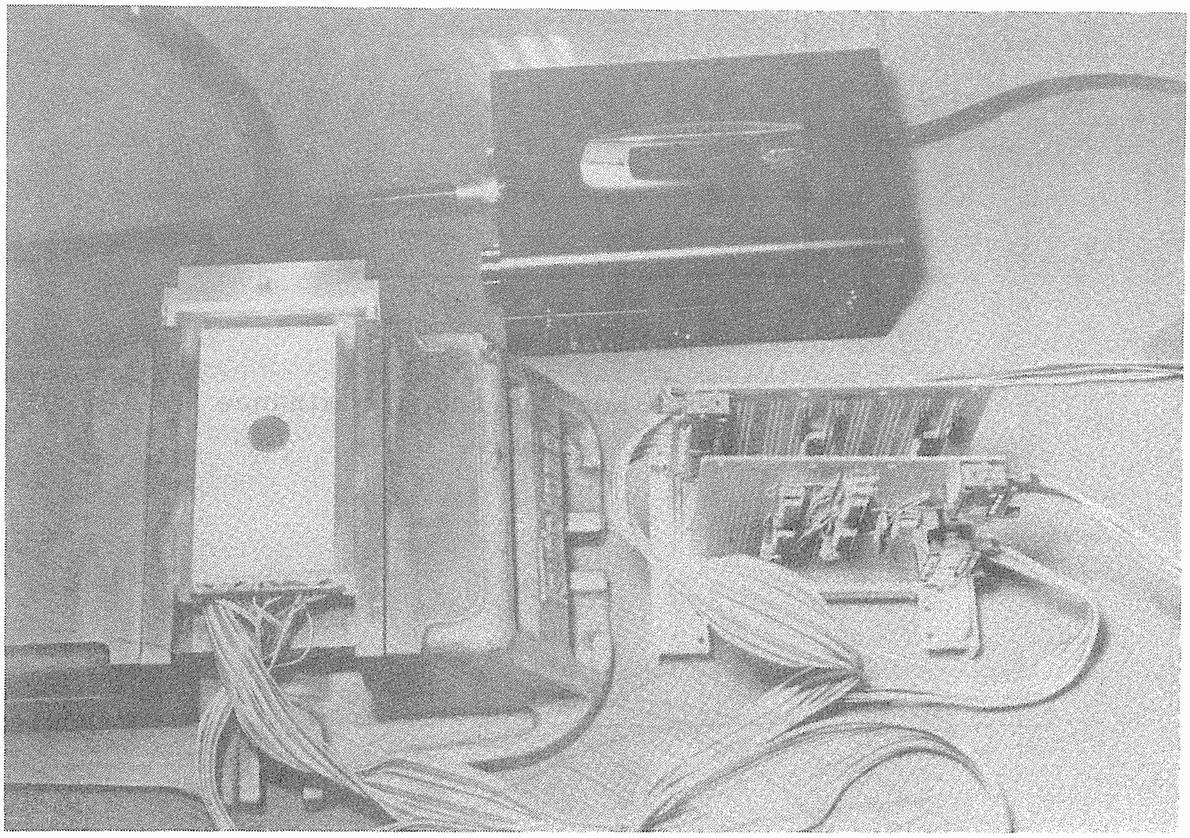


Fig. 8 Experimental Setup

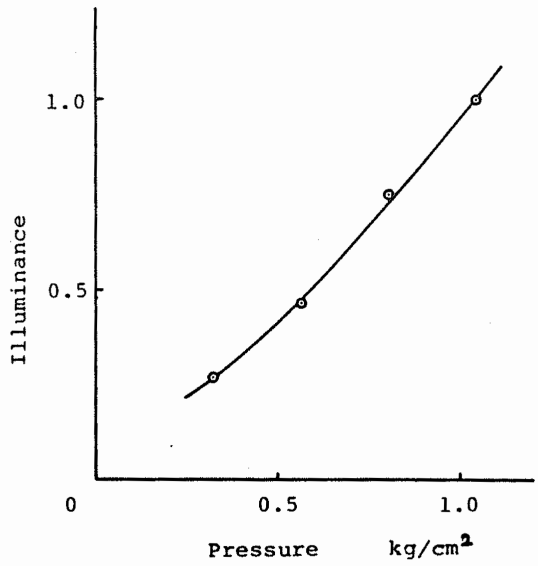


Fig. 9 A Relation between the illuminance and Applied Pressure

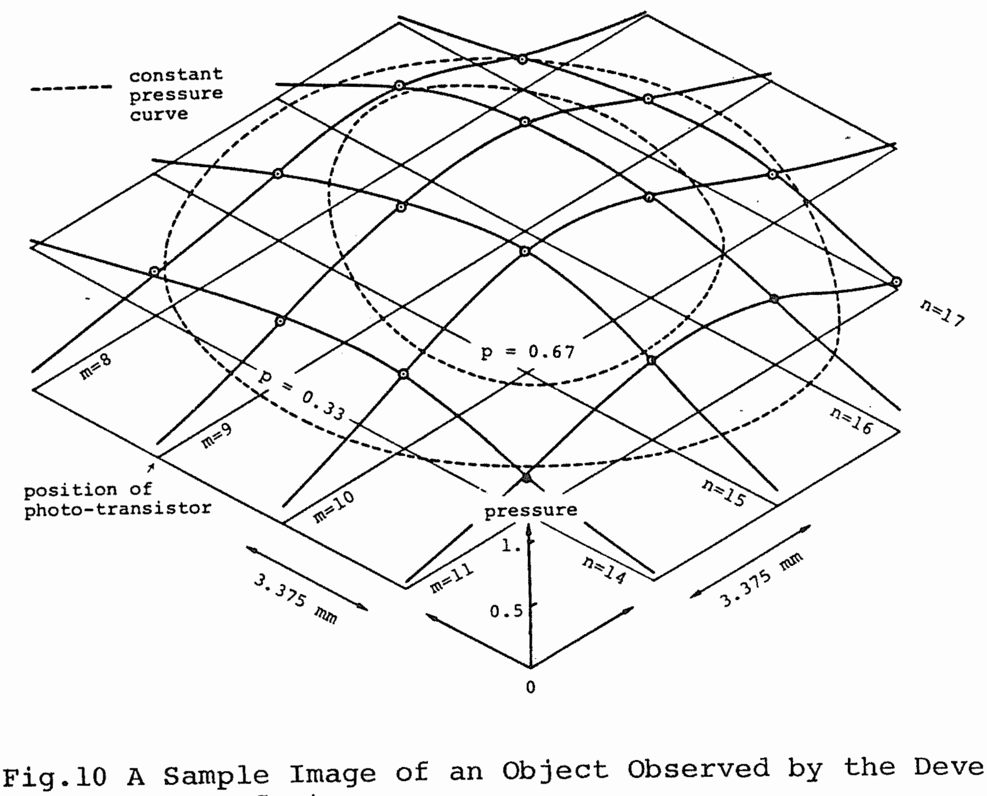


Fig.10 A Sample Image of an Object Observed by the Developed Sensor System