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A Robust, Sensitive and Economical Tactile Sensor for a Robotic Manipulator

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Abstract

This paper presents the progress of a project to create a robotic gripper specialised to gather haptic information. The lack of suitable ready made tactile sensors has meant that the initial stages of the project have concentrated on developing a sensitive, robust and economical tactile sensory skin. This sensor array utilizes the properties of optical dispersion and mechanical compliance of urethane foam in conjunction with an array of optical transmitters and detectors. The complete array forms a compact tactile sensory skin. Results are presented showing the output generated by the sensor array for different object shapes as well as sensitivity and linearity plots.. A proposed gripper design for use with the tactile sensor array is also presented.

1 Introduction

In automation processes, the sheer diversity of applications for a general purpose gripper require it to have the ability to grasp and identify shape, surface texture, force and slippage. The sense of touch, one of 5 human senses (vision, hearing, smell, taste and touch), provides particular information that cannot be perceived by any of the other senses. Touch may interpret object texture, hardness and temperature as well as the mechanical state of an object such as vibration or movement.

The sensory skin described in this paper provides a compliant surface for the gripper. Russell (1990) showed that for all but very flat objects, rigid tactile sensors provide very little information. Many household objects only make a small number of point contacts on a gripper surface. A compliant sensor skin would allow an object to indent into the sensor surface so that the area contacted is increased and thus increase the surface information gathered by the sensor.

The literature contains many reviews of tactile sensor technologies. In an early survey paper [Harmon, 1982] the following characteristics were proposed for a useful skin-like tactile sensor array:

- Array sizes between 5x10 and 10x20 points
- Threshold sensitivity between 5 and 10 g per sensor element
- A dynamic range of 1000:1
- Repeatable sensor response with no hysteresis
- Sampling rate between 100Hz and 1kHz
- Robust and in-expensive

Recently, as observed by Lee & Nicholls [1999], in tactile sensor design there is a shift away from novel sensor technologies and designs and towards the engineering of sensors. This approach yields sensor systems that are reliable, robust, and durable and have respectable overload capability.

In this paper a tactile sensor array is proposed that is designed to be applied to the contact surfaces of a robotic gripper. Many different types of robotic grippers have been developed. The usual approach has been to create a gripper system and then add tactile sensing capabilities later. In this project the order is reversed. The sensor system described in this paper effectively allows the tactile sensing system to be specified and when that is fully developed gripping capabilities will be added. In such a system the requirements for gathering touch sensory information will be given precedence over gripping and manipulation. The measurement of gripper force is also be considered. Craig [Craig, 1989], describes the issues relating to designing sensors for force measurement as defining resolution, good sensitivity and protection against mechanical overload whilst maintaining gripper stiffness.

3 Existing Tactile Sensor Technologies

Many different sensing techniques have been considered for the design of robot tactile sensors. For a brief review of the subject it is best to consider those sensor designs that have been developed into a commercial product. Probably the earliest example of a commercially produced robot tactile sensor is the Lord Corporation LTS200 [Rebman and Morris, 1986]. This sensor utilises an electro-optical technique and is not very sensitive. It contains many parts causing reliability to be an issue and increasing cost. This device is no longer in production. Another obsolete technology, the Model 300-16X16B made by Bonneville Scientific Inc uses an ultrasonic depth gauge measure the thickness of a rubber skin situated between the sensor and the manipulated object [Grahn and Astle, 1984]. The system worked very well but was also expensive. The ABER Intelligent Systems Mark 1 tactile robot gripper is a high resolution sensor system based on frustrated internal reflection. A similar sensor is described by King and White [King and White, 1985]. The combined gripper/sensor system however is too bulky for many applications. Interlink Electronics Inc. force sensing resistors are inexpensive when used in large quantities and are being used commercially as joystick and touch pad components. However, for small prototype production runs they are prohibitively expensive.

2 Design Concept

The advantage of the sensor developed for this project is its simplicity and robustness. The sensor is fabricated from urethane foam and an array of surface mounted IR emitters and detectors. The foam layer forms an optical cavity above the emitter/detector array. The optical devices are mounted upon a circuit board below the layer of polymer foam. Compression applied to the surface of the cavity causes a change in its optical properties. The change is proportional to the amount of deformation applied to the cavity surface. Reimer and Baldwin [Reimer and Baldwin, 2000] describe the optical cavity as an isotropic scattering medium. The urethane foam is composed of many closed cells. Light radiation entering the foam medium encounters the cells as large scattering particles. In this instance the size of the scattering particle is much larger than the wavelength of the radiation and so the radiation is scattered isotropicaly [Van De Hulst, 1964]. Each of the IR emitters on the circuit board becomes an optical source and is surrounded by a halo of scattered energy.

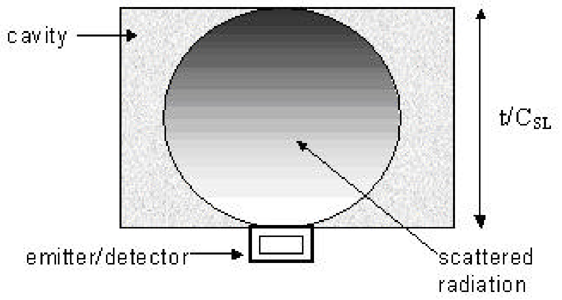

Figure 1 - Uncompressed optical cavity

As shown in Figure 1 the intensity of the energy scattered through the cavity is a function of the scattering and absorbing characteristics of the cavity. Reimer and Baldwin define the scattered radiating energy as

$$E_S = E_O[1 - e^{-t/CSL}] \tag{1}$$

Where E_O is the incident energy, E_S is the scattered energy and t is the thickness of the cavity. C_{SL} is termed the characteristic scattering length. The term t/C_{SL} is a normalized dimension. As the cavity is compressed, the value t is reduced and the property C_{SL} is proportionately reduced. However the ratio t/C_{SL} remains constant. The detector array effectively sees the integrated intensity of the scattered energy. As the optical cavity is compressed (see Figure 2), the intensity of the scattered energy increases.

This increase in energy is manifested as an increase in detector output. Polling of the detector array yields information on the level of deformation and the location of the deformation.

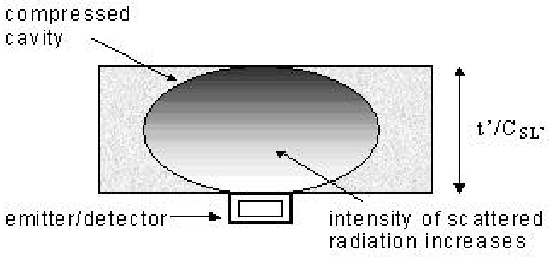

Figure 2 - compressed optical cavity

The sensor array is comprised of an array of 16 surface mounted, integrated infrared emitters and detectors. The peak wavelength of radiation is IR at 880nm.

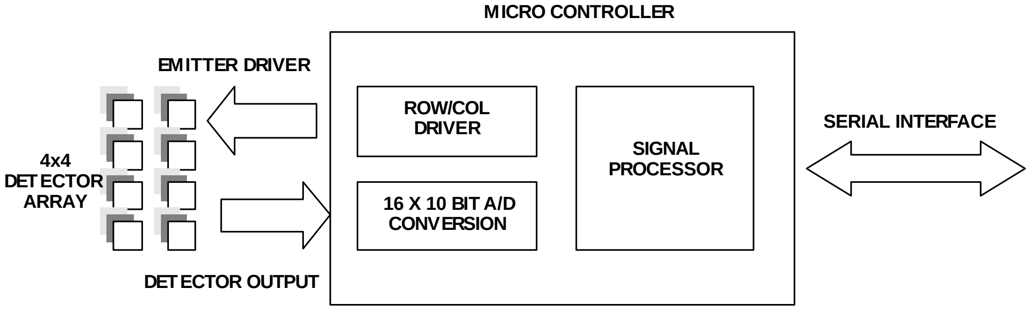

Figure 3 – A simple 8 bit microcontroller controls emitter drive and detector sampling, signal processing and data transfer to a host computer or master controller

Figure 3 shows the detector array controlled and configured by a simple microcontroller with on board digital I/O and 10 bit analog to digital (A/D) conversion. The microcontroller input and output lines drive a row and column-addressing scheme activating each of the emitter elements in turn. The array is electrically configured as a 4 element by 4 element array measuring 20mm square. The 16 detector outputs are then sampled by a 10 bit A/D converter internally multiplexed by the microcontroller. The sampled data is processed and transmitted to the host computer via a simple SPI serial interface. Using this simple configuration, multiple sensor arrays may be coupled to form larger sensing surfaces.

Figure 4 - Surface mount IR Emitter/Detector

A laptop PC processes the converted result and the data displayed in real time. Using this multiplexed scheme, virtual sensors may be implemented in software such that optical change within the cavity may be processed from several detectors within the halo of scattered radiation.

As shown in Figure 4, each detector element incorporates a IR emitter and an IR detector. The complete emitter/detector is a surface mounted device measuring around 4mm square.

In the experimental results that follow, a virtual sensor was constructed between each of the actual sensor elements. Even though the emitter array remains at 4x4, the detector array is processed over 7x7 elements. The following results show the output from a single array. Implementing the simple serial link between array controllers and linking subsequent array outputs within software allows the implementation of much larger sensing surfaces.

3.0 Experimental Results

As is seen in Figure 5, the sensor array returned a linear response for up to 30% compression of the optical cavity. Beyond 30% compression, the sensor array output flattens due to the crushing and collapse of the urethane foam cells.

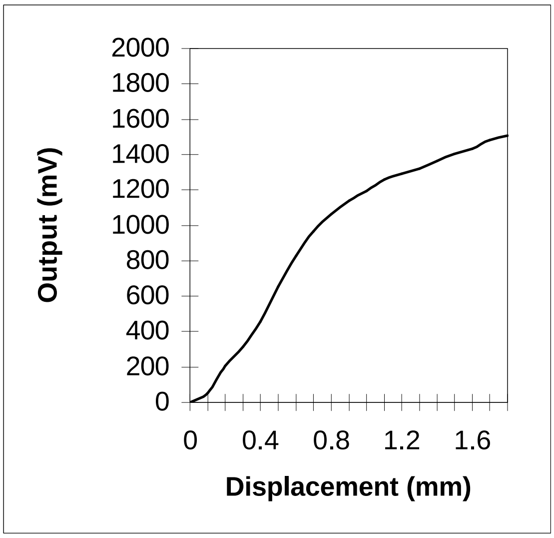

Figure 5 - Displacement v Output for 2.5mm Urethane

Figure 6 shows one frame of the real time output of the sensor array when a 25mm hollow tubular object was applied to the top surface of the urethane optical cavity.

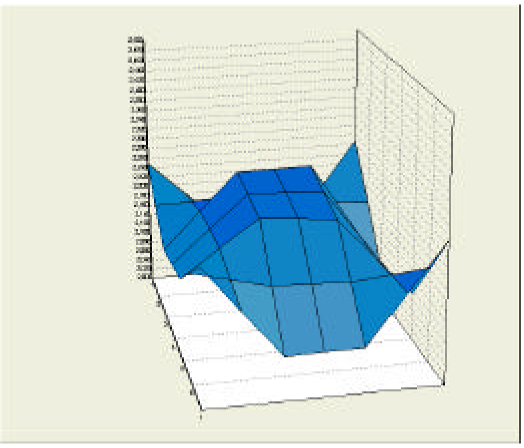

Figure 6 – Tubular object applied to cavity surface

Figure 7 shows another frame of the real time output of the sensor array produced when a hard edge was applied to the top surface of the urethane optical cavity. The hard edge was applied across the centre of the cavity to a depth of 0.5mm. The depressed regions of the plot provide a good representation of the indented edge.

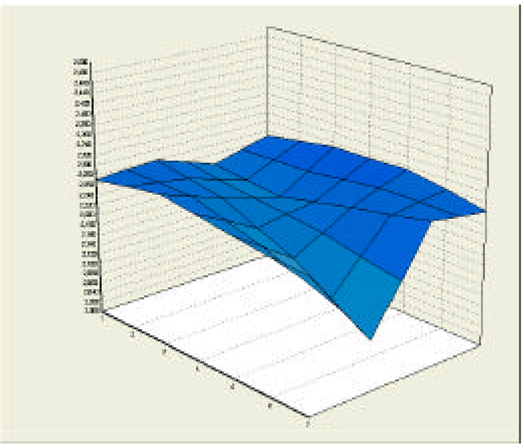

Figure 7 – Hard edged object indented into the cavity surface

4.0 Array Applications

It is envisaged that the sensor arrays will be mounted on the palm and finger surfaces of a simple manipulator. A preliminary diagram of the probable form of the gripper is given in Figure 8. When sensing the gripper would open out flat and present the sensor equipped surfaces of the fingers toward the object. This would allow the tactile sensors to make first contact and help the system to explore the unknown object. Once the object profile has been assessed, the fingers would be realigned and the manipulator used in a standard gripper function. This time the sensor array on the inner gripper surfaces would supply the manipulator with gripping pressure feedback for the object. The manipulator need only be of simple design and dextrous enough to perform simple manipulation operations. With the different gripper surfaces employed in detection, different surface shape styles may be used. Ridges and raised areas may be used on the outside of the gripper improving spatial resolution for a brushing sensor movement. Ribbed or domed surface shape styles may be applied to the inner gripper surface so that fine detail may be detected when manipulating the object and sensing pressure of the gripper jaws. This detection scheme aides in the detection of object slippage between the gripper fingers.

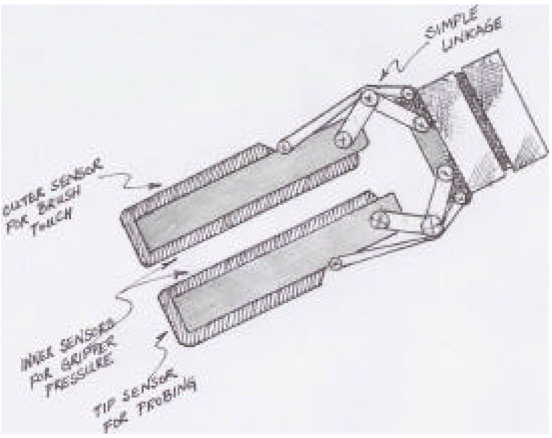

Figure 8 - Simple Gripper with applied sensors

Conclusions

The principles of operation and the performance characteristics of a simple and robust touch sensor have been presented. This principle could be applied to make simple touch and bump sensors for many robotic applications. Using thin urethane to form a compliant cavity together with flexible circuit building techniques, the sensor may be applied to curved as well as planar surface.

The nature of the compliant foam though does give cause to the sensor suffering from tactile inversion. The compliant surface essentially acts as a low pass filter. Only large-scale spatial patterns are sensed and fine detail may be attenuated. This problem may be overcome by use a shaped urethane surface. A surface featuring ribs or raised features would enhance the sharpness and resolution of features far better than a uniform sensing surface.

Future work will be applied to the shape of the detection surface to improve spatial patterns and to increase resolution. Also research will continue into the integration of the sensor into a simple robot gripper and to determine the suitability of the sensor array for attachment to curved surfaces.

Acknowledgements

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