A Tactile Sensor Array that also Grasps Objects

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Abstract

This paper describes a project aimed at developing a robotic tactile sensor system that can also manipulate objects. The usual approach to the problem of touch mediated (haptic) grasping and manipulation is to develop a highly complex dexterous gripper and then to attempt to retrofit a tactile sensing capability. This approach has not proved particularly successful and so in this project the priorities have been reversed to seek a better solution. A compliant palm-like tactile sensor array has been developed and then simple fingers added to provide a limited capability for grasping and manipulation. The tactile sensor array is made up of 80 sensory tiles each incorporating a separate microcontroller. When attached to a SIR 1 robotic manipulator arm the sensory gripper can locate and pick up objects using touch sensory information.

1 Introduction

Since the invention of the digital computer well known trends of miniaturisation, reducing power consumption and falling cost have occured. These trends see us today with microprocessor devices approaching the status of standard circuit components such as voltage regulators and operational amplifiers. This presents unprecedented opportunities for applying distributed processing power throughout system designs. This paper describes a novel robotic tactile sensor that makes use of large-scale distributed processing power by employing an array of 80 microcontrollers to implement a robotic tactile sensor array. The development of a dexterous sensory gripper with grasping and manipulation capabilities approaching those of the human hand is a current goal for several research groups around the world. A common approach is to construct a complex human-like dexterous gripper such as the Utah/MIT dextrous hand [Jacobsen et al. 1986] or Stanford-JPL [Salisbury, J.K. and Craig, J.J., 1982] and then attempt to retrofit tactile arrays to provide touch sensory feedback [Fearing, 1987] [Allen, 1990] . A very complex mechanism is required in order to produce a robotic gripper that even approaches the sophistication of the human hand. This mechanical complexity is difficult to accommodate within a gripper with human-like proportions. As a result there is little if any additional space to mount sensor pads or accommodate conduits to route data communications to the sensors. As a result only limited sensing can be incorporated into this kind of gripper. This is one of the reasons why current attempts to develop dexterous sensory grippers have not been notably successful. In this project the priorities have been turned around and rather than building a complicated gripper and then adding tactile sensing we have developed a sensor array with added gripping capabilities in the hope of producing a more viable robotic tactile sensing and manipulation system.

2 The Tactile Sensing Principle

Very stiff and rigid tactile sensors allow an object to be grasped in an accurately known position. However, there are a number of advantages to be gained from employing tactile sensors with a compliant surface. Such a flexible surface is closer to the consistency of the palps of a human finger and mould to the shape of a grasped object [Russell, 1990]. This compliance increases the area of contact thus providing a more stable grasp and more tactile information. In order to produce a compliant tactile sensor we used the principle of varying backscattered light from a urethane foam material [Hellard and Russell, 2002]. The 2.25mm thick foam is illuminated by the LED in an SFH2771 optical emitter/detector device [Anon, 2000]. Cells in the foam act as particles that scatter light back to the phototransistor in the SFH2771. As the foam is compressed the scattering points come closer to the detector and light intensity increases. In each touch-sensitive element or taxel of the sensor array power to the LED is controlled by pulse-width modulation so that the average illumination power can be varied. The signal from the phototransistor is passed through a first-order RC filter to remove the modulation frequency before routing the signal to an Analogue to Digital Converter (ADC) input on the ATtiny 26 microcontroller (Figure 1). Connecting the phototransistor in the SFH2771 in reverse mode gives a better match to the filter components compared to the more conventional forward connection.

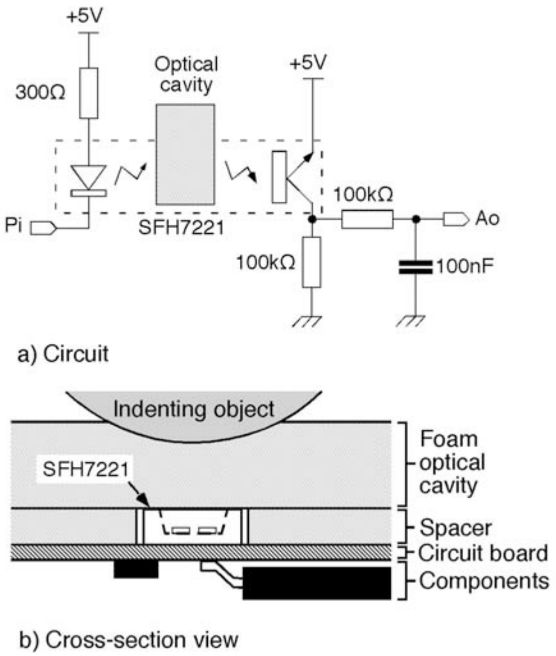

Figure 1 One touch-sensitive element in the sensor array.

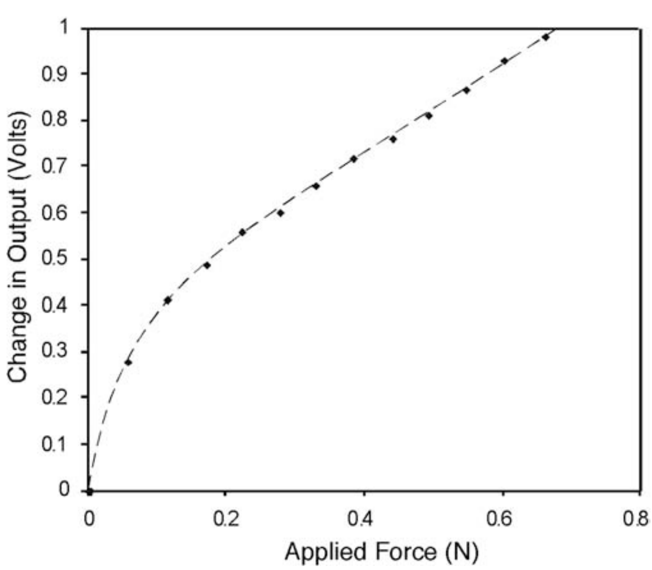

Figure 2 The relationship between applied force and change in output voltage for one taxel of the sensor array.

To measure the characteristics of one taxel, a varying mechanical load was applied to the foam directly over one optical emitter/detector. The load was transferred via a 10mm diameter flat-ended circular rod. The relationship between applied force and output voltage for one taxel is shown in Figure 2. In this graph the voltage axis is offset by the value of the sensor output for no load (2.2V). Initially there is a rapid change in sensor output with applied load. Above a load of about 0.1N the change in sensor output is almost linear with applied force. The sensor response could be linearised to some extent by preloading the array. However, this would be at the expense of reducing the initial high sensitivity. When the applied force becomes sufficient to collapse most of the cells in the foam the sensor 'saturates' and there is little additional increase in sensor output as more load is applied. The foam material provides a stable gripping surface with moderate friction and good resistance to wear.

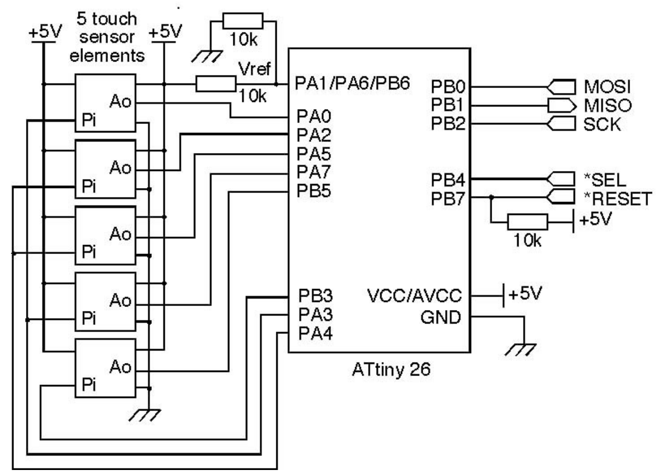

Figure 3 The circuit contained in one sensor tile.

3 The Sensor Tile

Each sensor tile contains an Atmel ATtiny 26 microcontroller [Anon, 2006] interfaced to 5 touch sensor elements. One ADC channel is allocated to each sensor element but to save I/O pins diagonally opposite sensor elements share an output pin and their LEDs are therefore on at the same time.

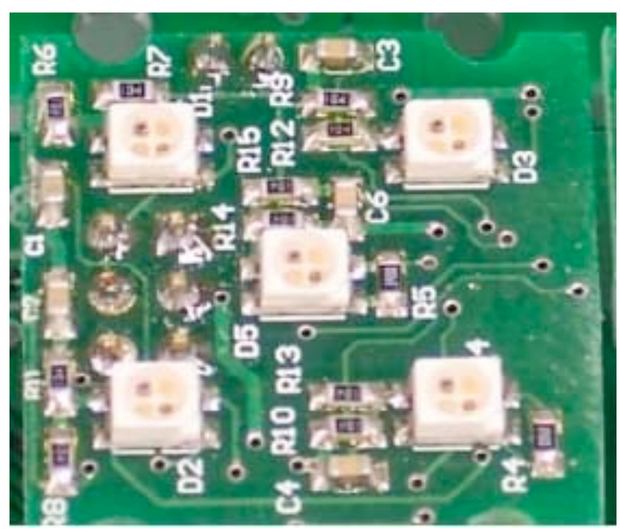

Figure 4 The sensing side of one sensor tile.

When interrogated the tile reports on the status of its 5 physical taxels and from those values a further 4 simulated taxel values are produced. The simulated values are calculated by averaging the output from the 3 adjacent taxels on the same tile. This results in 9 taxels with a centre to centre spacing of 7.5mm. Figure 4 shows the sensing side of one 22mm by 22mm tile. In operation the sensing side of the sensor tile is covered by a rectangle of urethane foam material. The other side of the sensor tile carries the microcontroller and connectors for plugging into the motherboard as can be seen in Figure 5.

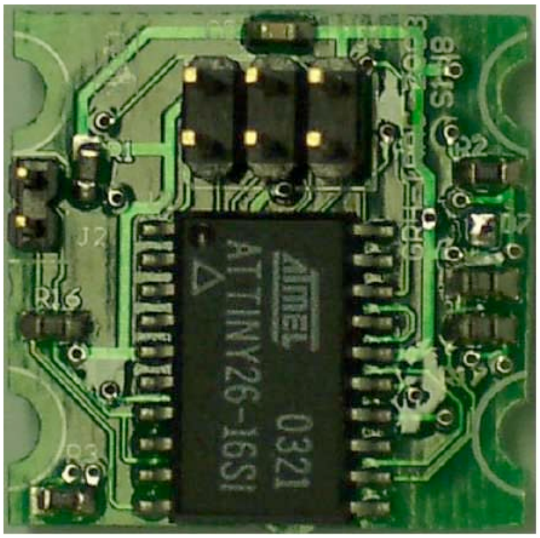

Figure 5 Component side of the sensor circuit board.

3.1 Sensor Communications

The tactile sensor array contains an 8 by 10 array of sensory tiles. In order to communicate with the tiles an SPI interface [Spasov, 2004] was implemented between the tiles and the parallel port of a PC. The SPI transfer is illustrated in Figure 6. The PC acts as a master and the sensor tiles as slaves. Two shift registers, one in the PC and one in the sensor microcontroller are interconnected so that after eight SCK cycles the data in each register is interchanged. The data in and data out transfers occur simultaneously. Input data is set up from the host PC and clocked to the receiving register of the sensor circuit on the rising edge of SCK. The falling edge of SCK clocks data from the sensor circuit output register to the PC. It will take 8 SCK cycles to transfer a byte of data between the host PC and the sensor circuit. The clock line, data input line and data output line are controlled by the PC and are common across all slave units (the sensor tiles). The sensor software enables the local data output when the sensor software detects a valid chip select for the particular sensor tile.

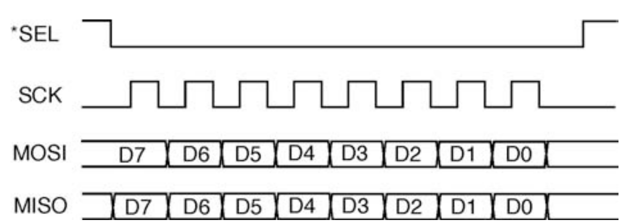

Figure 6 SPI interface protocol.

In order to be able to select one out of the 80 sensor tiles a chip select signal *SEL is generated by a chain of 74HC595 8-stage serial shift registers. As well as a shift register these devices also contain a storage register and have 3-state outputs. As illustrated in Figure 7 the chain of 74HC595s is controlled by the PC parallel port and this allows an arbitrary sensor tile or sensor tiles to be addressed by shifting in the appropriate bit pattern into the whole shift register. Sequential access is much simpler and only requires a shift signal followed by a latching operation to move from one tile to the next.

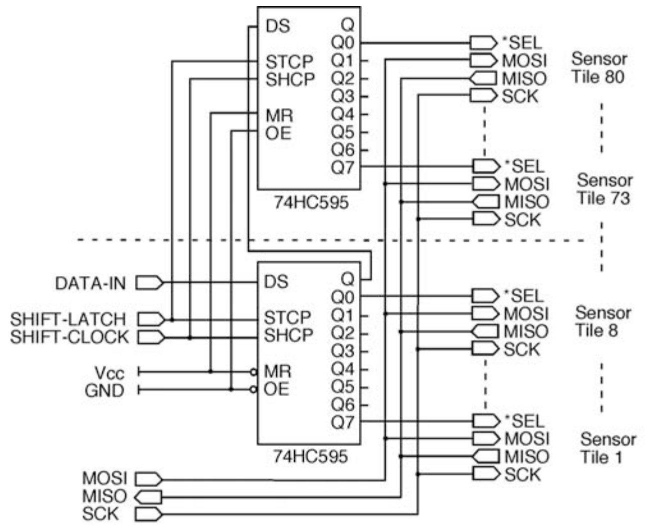

Figure 7 Sensor tile select circuitry.

3.2 Tactile Array

As we have seen, each tile supplies 5 physical taxel values and these are then augmented by calculating 4 interpolated readings to produce a rectangular array of 9 readings. The whole array can be read in 800ms and provides a rectangular 720 taxel image of objects indenting into the approximately 176mm by 220mm array. Figure 8 shows a sample tactile image from the sensor array as the array was pressed onto a rectangular block. The tactile array is a large flat sensor that can be likened to the human palm. As humans, when we are trying to find something by touch we tend to flatten the palm of one hand and then scan this over the region to be searched. If dexterous grippers are equipped with tactile sensors then they are usually in the form of a limited number of small patches. In addition, some dextrous grippers cannot be configured into a flat palm. Therefore, sensing with a flat palm is difficult or not possible for dexterous grippers.

In this project the priorities have been turned around and a flat palm-like sensor array has been developed. In order to investigate haptic manipulation the array has been augmented by adding simple grasping capabilities.

4 Construction of the Gripper

In the tactile sensor array the majority of the sensor tiles are mounted on a mother board which is then supported by an aluminium backing plate. To form gripping fingers two groups of four sensor tiles have been separated out and mounted on the tips of 2-degree of freedom fingers. The finger root servo is responsible for the gripping action of the fingers. Fingers are either retracted into the palm or brought together to perform a two fingered grasp. The finger tip servo controls the orientation of the finger sensing tiles. They are either turned parallel to the rest of the array while searching or maintained parallel to each other (the two finger tips) while grasping. Each finger articulation is actuated by a radio control servo. A PIC16C621 generates the pulse trains required to control the four finger servos. This microcontroller is interfaced to a serial port on the controlling PC.

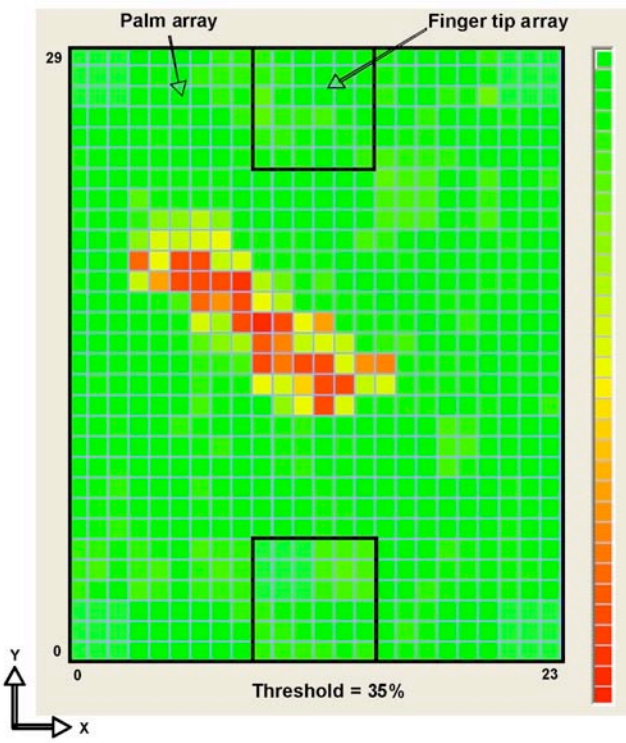

Figure 8 A tactile image produced by the tactile sensor array.

A side view of the sensor array and gripping fingers is given in Figure 9. During searching the fingertips can be retracted into the sensory palm to present a flat sensing surface. When an object has been located the gripper is moved to centre the object and then the fingers swing out of the plane of the palm and grasp the object. Figure 10 shows a tennis ball grasped by the fingers.

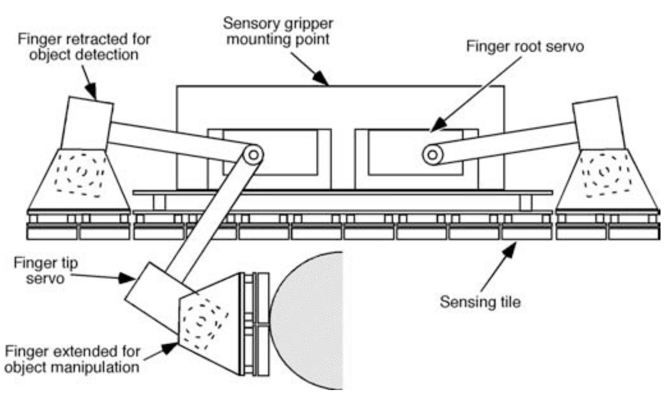

Figure 9 A side view of the sensory gripper.

5 A Demonstation Task

A simple sensing and manipulation task was devised in order to test the integration of the tactile sensor elements, gripper function and SIR 1 robot manipulator arm. The chosen task involved the location and grasping of a tennis ball.

5.1 Tactile search

As shown in Figure 11 the sensory gripper was mounted as the end-effector of a SIR 1 robot arm to provide mobility. In many situations a tactile search will involve scanning a planar wall, floor or tabletop to locate a salient object or feature. Locating the surface by touch can be performed by measuring the position of three points of contact as described in [Russell, 1989]. In this project the table top was assumed to lie in the x-y plane of reference of the SIR 1 robot. The reachable area of the SIR 1 robot was then searched by an overlapping sequence of guarded movements lowering the palm towards the table top and stopping when the sensor array registered a significant region of contact.

Figure 10 The sensory gripper grasping a tennis ball

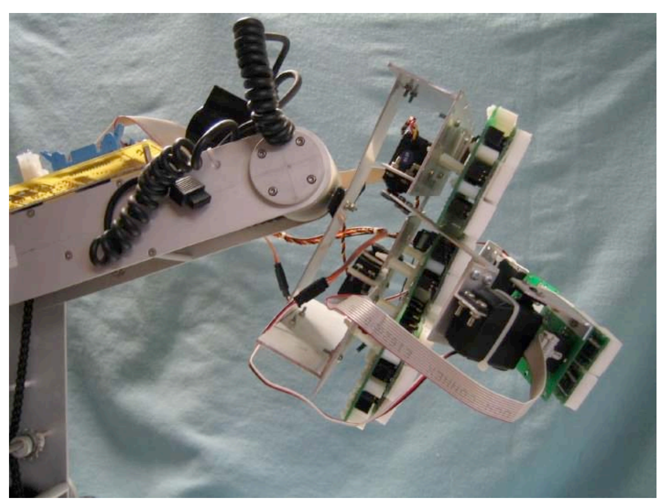

Figure 11 The sensory gripper and SIR 1 robot manipulator.

5.2 Processing the Tactile Image

Upon detecting contact with an object the tactile image was thresholded to produce a binary image using an experimentally found threshold level. Resulting binary image (with taxel t_{ij}=1 representing contact and t_{ij}=0 representing no contact) was then processed using moments of area [Winston and Horn, 1984]. Moment of area m_{pq} is defined as:

$$m_{pq} = \sum_i \sum_j i^p j^q t_{ij} \quad (1)$$

From the moments of area the location of the object with respect to the centre of the gripper and its orientation can be calculated. The *i* and *j* coordinates of the centre of a region of contact are:

$$i_0 = \frac{m_{10}}{m_{00}} \quad (2)$$

$$i_0 = \frac{m_{01}}{m_{00}} \quad (3)$$

The orientation of the the long axis of a blob (the axis of minimum moment of inertia) is given by:

$$\theta_0 = \frac{1}{2} \tan^{-1} \left[\frac{2(m_{00}m_{11} - m_{10}m_{01})}{(m_{00}m_{20} - m_{10}^2) - (m_{00}m_{02} - m_{01}^2)} \right] \quad (4)$$

There is an ambiguity in the calculation of the inverse tangent. However, the sign of both the numerator and denominator in equation 4 are known and therefore this ambiguity can be resolved (the atan2 function). For the task of aquiring a tennis ball only the centre of area of contact was considered.

5.3 Tactile Servo

The idea of tactile servo [Zhang and Chen, 2000] is to use data from a tactile sensing system as part of a control loop for guiding manipulation tasks that involve contact. As originally proposed tactile servo involved a robot maintaining contact with an object while it was being manipulated (usually involving rolling) to a desired pose. For the tennis ball acquisition task the gripper the tactile servo process was modified and involved raising the gripper from the ball, repositioning and then lowering again in order to centre the ball between the gripper fingers. Because contact was not maintained during this process there was the possibility that the ball would move during repositioning. This problem was countered by measuring the ball's position after repositioning to ensure that it was correctly located.

5.4 Grasping and Manipulation

In order to grasp the ball the gripper was again reaised to allow sufficient clearence for the fingers to move beneath the sensory palm. Contact and successful grasping were confirmed by monitoring the tactile image from each fingertip. The gripper could then pickup and manipulate the object as shown in Figure 10.

A number of small objects including a tennis ball have been successfully located and grasped using this procedure. This task demonstrates some of the capabilities of the sensory gripper.

6 Conclusions

This paper has described a novel robotic tactile sensing palm that has been designed with a compliant sensing surface mimicking the mechanical characteristics of the human hand. The sensing palm makes use of a distributed processing array composed of 80 Atmel ATtiny 26 microcontrollers. This array illustrates a trend of increasingly treating microprocessors like any other electronic component to be used freely throughout a design rather than as an expensive device to be employed only sparingly.

Two simple fingers have been incorporated into the sensing palm to provide elementary grasping capabilities. The entire device was then mounted on a SIR 1 robot manipulator arm to allow it to be positioned as required for sensing and manipulation operations. It has been demonstrated that the resulting sensory gripper system can be used to locate objects by a tactile search. The tactile image produced by the sensing palm can be used to help locate and recognise objects as well as detect their presence. After locating an object the sensory gripper can be centred over the object. From this position the fingers may be swung down to grasp and manipulate the object.

In future work we would like to use the distributed processing capability of the sensing palm to perform additional data manipulation tasks such as averaging the sensor output and comparing each sensor value against a fixed threshold to warn of contact without having the central PC scan the entire array. The current size of the sensory gripper was dictated by the use of readily available components and is about two and a half times larger than a human palm. This presents no problem when manipulating relatively large objects such as a tennis ball. However, many smaller objects that can be readily grasped by a human hand are too small for the gripper fingers. Therefore, a size reduction of about 2.5 times will be aimed for while maintaining the original number of taxels.

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