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Discriminative Touch from Pressure Sensors

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***Abstract*—Touch is an important sensory pathway for exploring the world, but most robotic systems either have no sense of touch, use simple binary bump switches, or require expensive custom sensors. In this work we investigate the use of low-cost sensors to acquire more discriminative representations of touch sensations. We show that using two pressure sensors in a 3D-printed housing we can determine the location of a touch along a one dimensional axis. Furthermore, we can distinguish between different types of touches by the profile of the sensor response.**

I. INTRODUCTION

Touch is one of the five primary human senses and is integral to our understanding of the world. It is almost unthinkable that humanoid or animal-like robots would not also require a similar sense. Indeed, there has been much work on developing such sensors for robotics and other applications, see [1] for recent reviews. Despite the amount of work, there is still no system that approaches the performance of the human hand and is also cheap and therefore easy to manufacture.

The rise of cheap 3D printing solutions such as the Up Plus 2 3D printer [2] has allowed for the development of very cheap robotic manipulators such as the Dextrus robotic hand [3]. Our work is on a much simpler robotic gripper and is not comparable to a full robot hand. Nevertheless, we investigate the use of a simple 3D printed gripper with just two sensors and show that this system can be used to distinguish between 5 distinct touch areas. We also show that such sensors can be used to distinguish between different types of touch. Our ultimate goal is to develop a cheap 3D printable robotic hand/gripper that is capable of distinguishing both where a touch is located to reasonable accuracy, and what sort of touch was encountered. We offer a small step in that direction in this paper.

II. PREVIOUS WORK

'Touch' is commonly used to describe the sensations we receive when we make physical contact with the world. This covers a wide range of sensations such as temperature (thermoreception) and pain (nociception) as well as pressure from contact with other objects (mechanoreception). In this paper we use 'touch' to refer to mechanoreception and make a distinction between crude touch sensation ("Is there a touch?") with fine or discriminative touch sensation ("Where and what sort of touch?").

Simple robotic systems use bump switches to sense touch, and these are popular in applications such as RoboCup competitions [4]. Physical contact with a bump closes a circuit, yielding a binary touch/no-touch measurement. Multiple sensors can be combined to give a more nuanced, but still discrete, set of touch sensations. Shanahan, for example, uses three touch sensors inside a circular shell or 'whisker' [5]. Such an arrangement gives 7 possible sensory states depending on which direction a touch comes from – there are $2^3 = 8$ switch states, but a single touch cannot close all three switches.

Fine motor tasks, such as grasping and manipulating objects, benefit from more advanced touch sensors. Four common types of touch sensors [6], [7] are piezoresistive, capacitive, piezoresistive MEMS, and optical. These are commonly embedded in some sort of two-dimensional array to give surface-based touch or force sensing, and often the array is flexible allowing for skin-like sensing. However, such solutions typically require bespoke manufacturing for each application and are hence expensive. Recently, low-cost touch sensors based on MEMS barometers have become available [8], [9]. These sensors, coupled with an Arduino micro-controller, allow for simple, configurable touch sensing applications through a USB interface, and are ideal for building touch sensing prototypes.

Dahiya et al. [10] offer 11 hints for the design of robotic tactile sensing including: spatial resolution for fingertips should be 1mm; sensors should demonstrate high sensitivity and high dynamic range; sensors should respond quickly; sensors should incorporate local preprocessing; sensors could be embedded in or covered with elastic material; linearity and low hysterisis are desirable. The TakkTile [11] sensors satisfy many of these properties, although spatial resolution of individual sensors is greater than 1mm (the physical sensor size is 5×3mm). As such, sensor interpolation/superresolution is required to achieve reasonable spatial resolution. Rosenberg et al.[12] show how bilinear interpolation can be used with a force sensitive resistive (FSR) array to create an accurate and cheap touch sensor. However, their application was for a touch pad for computer input, rather than robotics. van den Heever et al.[13] use multiple touch "images" and a simple super-resolution algorithm to improve the resolution of an FSR array. Such an algorithm could be used to improve touch resolution over time, but we are more interested in single touch resolution.

The contributions of this paper are the design of a simple yet practical robot gripper with elements allowing easy integration of MEMS barometer touch sensors. We use two sensors embedded in tracks along the gripper and in conjunction with a printed "skin"[1], show how these two sensors can be used to

[1] it is a thin, but rigid plastic covering, acting like a flexible beam rather than a deformable membrane.

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discriminate between 5 touch zones and also can be used to discriminate different types of touch.

III. Touch Sensor System

Our target application is a robot arm that will explore its environment using visual and mechanoreceptory (pressure-based touch) information. In this work, we consider just the mechanoreceptory aspects of the system, which is provided by MEMS-based barometric sensors on the robot's gripper. In this work we use TakkTile sensors [11] attached to a Commonplace Robotics Mover4 arm [14]. In order to attach these sensors, we have replaced the stock gripper with a 3D printed one of our own design. Figure 1 shows the design of the gripper and Figure 2 shows outer skin covers. The sensors are placed in a channel on the gripper and covered with the outer skin or whisker. In these experiments we use two touch sensors placed in the outer channel of the gripper. Figure 3 shows the actual gripper and the associated Arduino sensor controller. In the final application these will be used to detect when the arm has encountered an object or obstacle while moving through the environment.

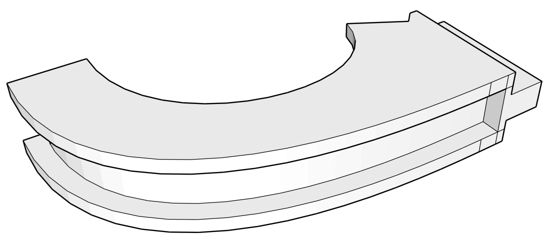

Fig. 1. Design model for one arm of the gripper design

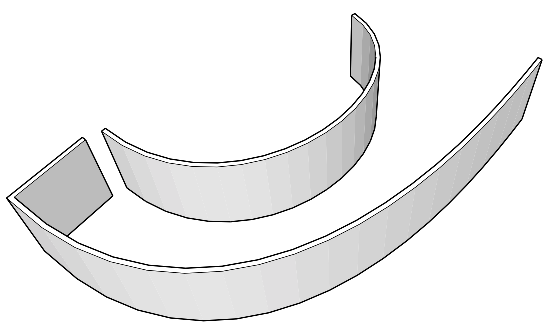

Fig. 2. Design model for outer skin of the 3D printed gripper

An idealised model of this system is that the sensors act as supports for a beam (the outer whisker) as shown in Figure 4. A force applied to the outer strip will cause a change in the pressure applied to each sensor. With reference to Figure 4, a touch in region A should cause an increase in pressure on sensor S_1, but no change in S_2; a touch in region C should increase S_2 only; while a touch in region B should increase the pressure on both S_1 and S_2.

IV. Locating Touches

Suppose that the sensors are unit distance apart, and a force, F, is applied at some distance, $d \in [0, 1]$, from S1 towards S2.

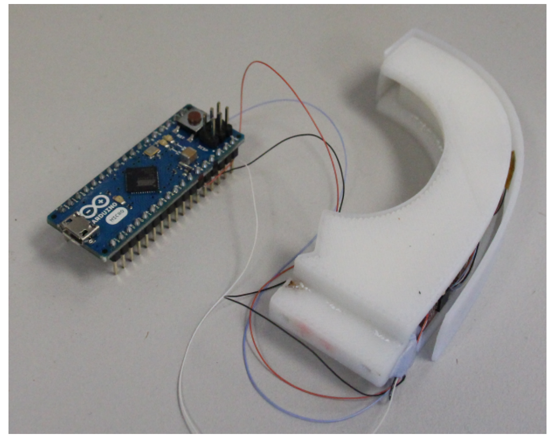

Fig. 3. The printed arm of the gripper with sensors and controller and outer skin

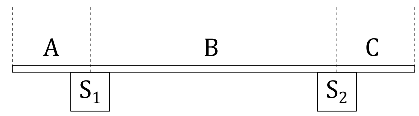

Fig. 4. Two sensors, S_1 and S_2, are connected by a whisker which can be modelled as a beam. In an ideal case, touch sensations in region A will only affect S_1; those in B will affect both sensors, and those in C just S_2.

This will lead to reaction forces, R_1 and R_2, at the two sensors. These forces keep the structure in static equilibrium, so

$$R_1 + R_2 = F. \tag{1}$$

However, the force may not be equally distributed between the sensors. This is because the sensors act as supports for a beam, so the moments around them must be balanced

$$d_f F = d_1 R_1, d_2 R_2, \tag{2}$$

where d_f is the distance to the applied force from some reference point, d_1 the distance to S_1, and d_2 the distance to S_2. If we take the position of S_1 as our reference, then we have $d_f = d$, $d_1 = 0$, and $d_2 = 1$, which leads to

$$R_1 = (1 - d)F \tag{3}$$
$$R_2 = dF. \tag{4}$$

Suppose the sensor reading at S_1 is s_1, and that at S_2 is s_2. If our sensor readings were proportional to these reaction forces, then we can solve for d directly

$$\frac{(1-d)F}{dF} = \frac{R_1}{R_2} \tag{5}$$
$$\frac{1-d}{d} = \frac{s_1}{s_2} \tag{6}$$
$$(1-d)s_2 = ds_1 \tag{7}$$
$$d = \frac{s_2}{s_1 + s_2}. \tag{8}$$

In practice the situation is not as simple as this for a number of reasons. The pressure sensors do not have a reading of zero when no force is applied, and their response does not depend solely on the magnitude of the force applied. As we show in

Section V, the sensors have a 'memory' that takes some time to reset, and different types of contact induce different response patterns.

In order to experimentally evaluate the response of the two sensors to pressure at different places, we define a set of zones spaced along the outer edge of the gripper. These seven zones are shown in Figure 5, and a series of touches was performed in each zone. Since very strong forces can saturate the sensors, we controlled the force of each touch by depressing a plastic head attached to a spring by a constant distance in each trial. The sensors do not give a zero-reading when no pressure is applied, so their baseline response is subtracted from the recorded pressure readings. Given a raw sensor reading, r_i, for sensor S_i, we take the sensor measurement to be $s_i = r_i - b_i$, where b_i is the baseline reading of S_i when no force is applied.

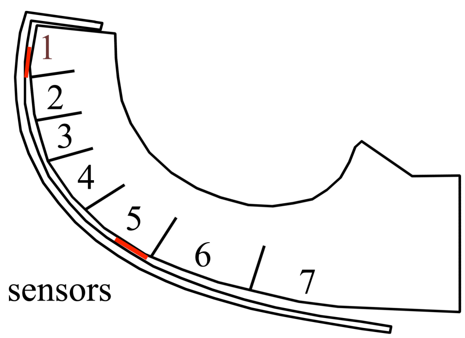

Fig. 5. Diagram of the gripper showing sensor placement

Figure 6 shows the ratio of sensor readings, $\frac{s_1}{s_2}$ for each zone. There is a general decrease, although it is hard to see if this holds beyond zone 3. Also there is a very large spread of values in zone 1. Both of these effects come from the use of a ratio. When the touch is close to S_1, s_2 is very small, and therefore noisy. This results in a large spread of values in $\frac{s_1}{s_2}$. Conversely, when the touch is close to S_2, s_2 is very large, so the ratio approaches zero.

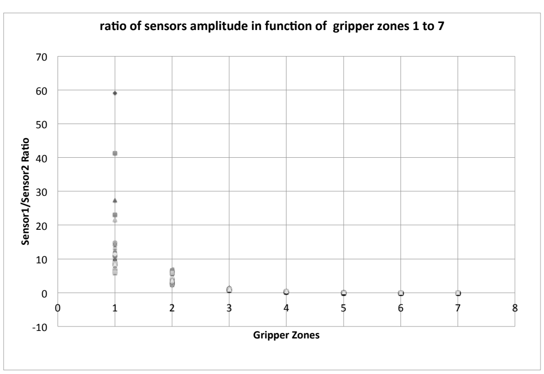

Fig. 6. Ratio of sensor readings in each zone

These issues can be overcome by taking a logarithm of the ratio:

$$\log\left(\frac{s_1}{s_2}\right) = \log(s_1) - \log(s_2). \quad (9)$$

A plot of the logarithm of the ratios is shown in Figure 7 This shows a much clearer progression, and more uniform spread. Note that the sensory response in zones 6 and 7 are very similar. This is because they are on the other side of S_2 to S_1, and so almost all of the force is applied to S_2.

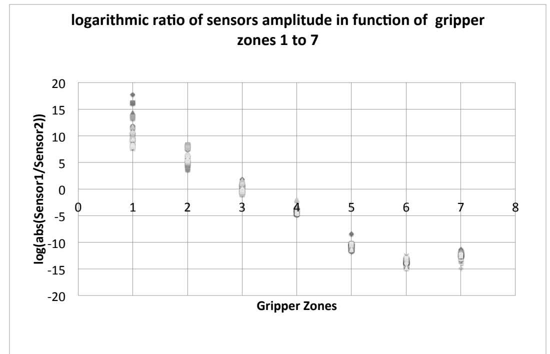

Fig. 7. Log ratio of sensor readings in each zone

V. Types of Touch

The response from the sensors in response to a touch is not a simple impulse or box function. Figure 8 shows the result of brief, but firm pressure being applied to S_2. The sensor's readings drop in response to pressure, which is the sharp decrease around 2s. However, when the pressure is being released, the response increases past its original value, and it takes some time for this to return to its original state.

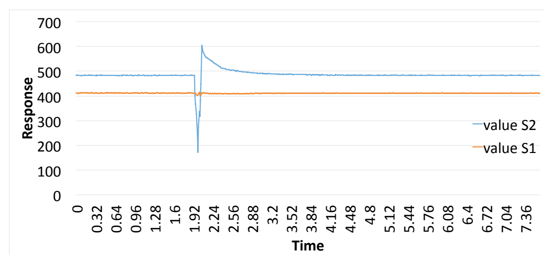

Fig. 8. Sensor response to a brief, but firm, touch at Sensor 2

How long it takes the sensor to recover depends on the amount of force applied. Figure 9 shows the time taken to return to within 5% of the original sensor reading after contacts with various forces. The force of a contact is measured by the maximum amount of depression from the baseline reading. As can be clearly seen, the recovery time is longer for greater forces, but more experiments are required to determine the exact nature of this relationship.

The qualitative nature of the touch also has an effect on the sensor responses. The touch in Figure 8 is a deliberate press and release directly over S_2. This causes a strong response from S_2, but has practically no effect on S_1. If, however, we apply a sharp tap to S_2 with a hard object, we see a very different outcome, shown in Figure 10 S_2's response is depressed, as before, but stays low for a longer duration, probably because of shape memory of the rubber casting.

Interestingly we see a response in S_1 as well as S_2, but in the opposite direction. This is due to a shock-wave caused by the sharp impact. This travels down the whisker and triggers a response in S_1.

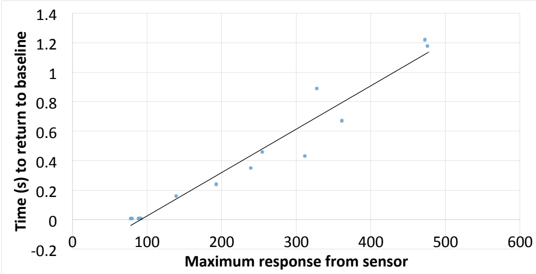

Fig. 9. Time for the sensor to recover versus the initial sensor response

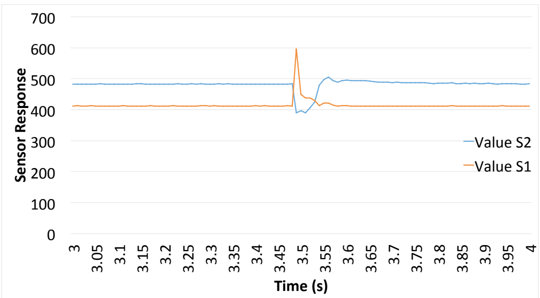

Fig. 10. Sensor response to an impulse force at Sensor 2

VI. Conclusions and Future Work

In this paper we have investigated the use of low-cost MEMS sensors for robotic applications. We have shown that they can provide discriminative touch sensations, determining both the location and type of touch. This is in contrast to crude touch sensation, which merely indicates the presence or absence of a touch.

There is clearly scope for much future work. In particular, the extension of the system to two-dimensional areas would be worth investigating — such a system could be appropriate for touch sensors on the back of a robotic hand for example (resolution requirements are not as great there). It would also be interesting to see the response of the sensors to a deformable skin rather than the rigid skin used in this study. In particular, since the sensors are cast in rubber in any case, it should be straightforward to embed them in the gripper un-cast, and then subsequently cast the entire assemblage in rubber, or a similar flexible compound. If simple interpolation or zone discrimination was still possible, this would be an interesting solution.

Acknowledgment

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