Experiments with Haptic Perception in a Robotic Hand

Magnus Johnsson[1,2]
Robert Pallbo[1]
Christian Balkenius[2]

[1]Dept. of Computer Science and [2]Lund University Cognitive Science
Lund University, Sweden

Abstract

This paper describes a robotic hand, LUCS Haptic Hand I, that has been built as a first step in a project aiming at the study haptic perception. Grasping tests with the hand were done with different objects, and the signal patterns from the sensors were studied and analyzed. The results suggest that LUCS Haptic Hand I provides signal patterns that are possible to categorize. Certain higher-level properties were found that can be derived from the raw data that can be used as a basis for haptic object categorization.

1 Introduction

Identifying materials and objects using the perception of touch in our hands is an ability that we often take for granted, and normally we hardly think about it. But to be possible, this ability demands a hand with a very sophisticated ability to manipulate grasped objects. It also needs receptors for several submodalities, especially cutaneous and proprioceptive mechanoreceptors Gentaz (2003). In addition, neurophysiological systems are needed, that can actively choose a way to manipulate the object in a beneficial way and then control the execution of these manipulations, while at the same time receiving and categorizing sensory data (Gardner & Kandel, 2000; Gardner, Martin & Jessell, 2000).

One way to learn more about how such an ability works and to find applications for that knowledge by reversed engineering, is to try to build an artificial haptic system with the abilities mentioned above. Such as system should use the human hand and brain as a prototype. This is what we have the ambition to do.

The main focus of the research on robotic hands has been on grasping and object manipulation (DeLaurentis and Mavroidis, 2000, Sugiuchi, Hasegawa, Watanabe and Nomoto, 2000, Dario, Guglielmelli & Laschi, 2001, Laschi et al., 2002, Dario, Laschi, Menciassi, Guglielmelli, Carrozza & Micera, 2003, Rhee, Chung, Kim, Shim & Lee, 2004) and surprisingly little work has addressed the problem of haptic perception and only a few haptic perception systems have been built. One example is a system capable of haptic object classification (Dario et al., 2000). This system has obtained object classification with the aid of touch and vision, by replicating the human ability to integration of sensory data from different modalities into one low-level perception, so that object recognition can be obtained without any interference from high-level cognitive processes. The system consists of two levels of neural networks: the first level for feature extraction from the tactile and dynamic signals, and the other, that is fed with output from the previous level of neural networks, output from a visual recognition module and with direct thermal sensor output, aims at recognition.

Okamura, Turner and Cutkosky (1997), have developed a method for haptic exploration of unknown objects with a dextrous robotic hand. The method uses a sequence of phases in which some fingers grasp and manipulate the object, while the other fingers roll and slide over the surface. With the aid of sensors, the rolling and sliding fingers can detect the features of the object surface.

A number of algorithms for the detection of tiny features like ridges and bumps on the surface of an object have been tested together with a robotic finger equipped with a hemispherical fingertip by Okamura and Cutkosky (1999). An interesting result from these tests is that the detection of the features of a surface are facilitated by the information received from tracing the trajectory followed by a round fingertip that rolls and slides over the surface.

As a beginning of our project to explore haptic perception, we have built the LUCS Haptic Hand I, which is a very simple robotic hand equipped with a tactile sensory system. The aim of building this hand was to gain experience that will enable us to build a more advanced and elaborate system later on. As a consequence, the sophistication of LUCS Haptic Hand I has been kept at a minimal level. However, the robotic hand makes it possible to generate tactile signal patterns while grasping objects that are differentiated enough to enable categorization with respect to, at least, hardness and size and possibly even shape. The first hand also fulfills the goal of generating realistic sensory input to the biologically inspired categorization system that we are building.

The rest of this paper will consider the technical design of the LUCS Haptic Hand I, and describes the analysis of the signal patterns received from it while it is grasping objects.

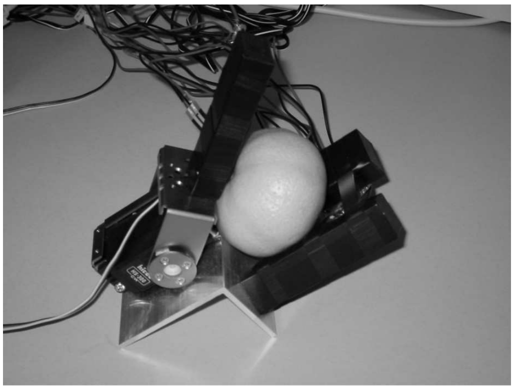

FIGURE 1: *The LUCS Haptic Hand I while grasping a mandarine. (A movie showing the LUCS haptic hand I while grasping an object is available on the web site, see Johnsson, 2004).*

2 LUCS Haptic Hand I

LUCS Haptic Hand I (Fig. 1) has three fingers and one of them, the thumb, is moveable with one degree of freedom. The fingers, that are made from Delrin acetal resin, are straight and rigid and of a rectangular shape (Fig. 2). The two fixed fingers are mounted so that their superior sides are slanted inwards. The thumb is mounted on a metallic joint that is controlled by a RC servo. Besides transmitting torque from the RC servo to the thumb, the metal joint also stabilizes sideway movements, so that the movement of the thumb becomes more accurate. When the thumb moves to close the hand, it ends up right between the two fixed fingers.

Each finger is provided with an array of three force sensitive resistors, attached to the fingers with equal distance in between, i.e. one sensor is placed at the outermost part of the finger, one sensor at the innermost part, and one in between (Fig. 2A). There are tiny plastic plates mounted on top of the sensors to distribute the forces on the fingers. These plastic plates are necessary because otherwise the pressure must be applied right at the push sensor. The size of the plastic plates is such that they fit within the borders of the tactile sensors. Every tactile sensor is, together with a capacitor and a resistor, part of a circuit, which generates a pulse with a length that depends on the pressure applied to the sensor.

LUCS haptic hand I communicates with the computer via the serial port, and as an interface a Basic Stamp II is used. The Basic Stamp executes a loop that in every iteration reads a message, coming from the computer, about whether the position of the thumb is going to be changed, and if so to what position. If the position is going to be changed, then a signal is sent to another board, a mini SSC II, which generates a pulse to the RC servo which then moves to the desired position. In every iteration of the loop the pulse length of the signals from each sensor is also read and sent to the computer.

All software for LUCS haptic hand I is developed developed as Ikaros modules. Ikaros provides a kernel and an infrastructure for computer simulations of the brain (Balkenius, 2004, Balkenius & Morén, 2003). So far the software consists of an Ikaros module that handles the communication on the serial port. In addition it orders a grasping movement of the robotic hand and receives information about the status of the sensors. As output a matrix is generated that represents the status of the sensors at different discrete points in time during the grasping movement.

3 Grasping Tests

We have tested LUCS Haptic Hand I by letting it grasp a number of objects (Fig. 1). The grasping of an object by the robotic hand consists of the movement of the thumb from an open position to a closed position.

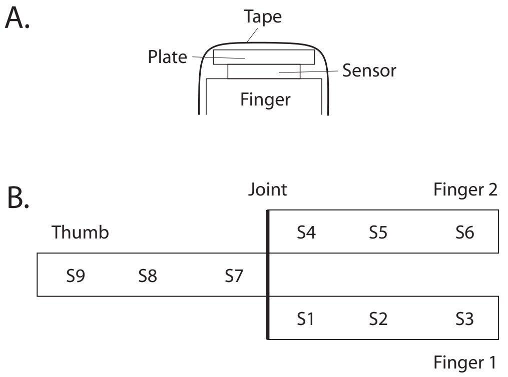

FIGURE 2: *The mechanical design. A. The design of the tactile sensors with a force sensitive resistor covered with a small plate that distributes the pressure on the finger. B. The placement of the tactile sensors. There are three sensors on each finger.*

The thumb is kept in closed position for a while and then it moves back to an open position again. The objects were selected as test objects, because in preliminary tests, the ability of the robotic hand to detect arbitrary shapes turned out to be severely limited. Different kinds of balls turned out to be especially suitable, and therefore such balls were selected to allow studies of the changes to the signal patterns due to hardness and size. To get a comprehension of the impact of the shape on the signal patterns, we also used two different cubes as test object. Both cubes are made of foam rubber, because other objects than those with a spherical shape were hard for the robotic hand to detect if they were not of a soft material.

The hand grasped each object, described in Table 1, 30 times. In each grasping test the object was placed in an identical way in the robotic hand. The results of the grasping tests have been presented in the form of diagrams showing the mean value of the signals, during the grasping, from the 30 grasping tests with an object together with the variance.

4 Results

Only sensor 1 reacted when the small cube was grasped, and the maximal strength of the signal was approximately 1400.

In the case of the big cube, only sensor 7 reacted, and the maximal strength of the signal was approximately 1600. We can also see that the signal is starting earlier

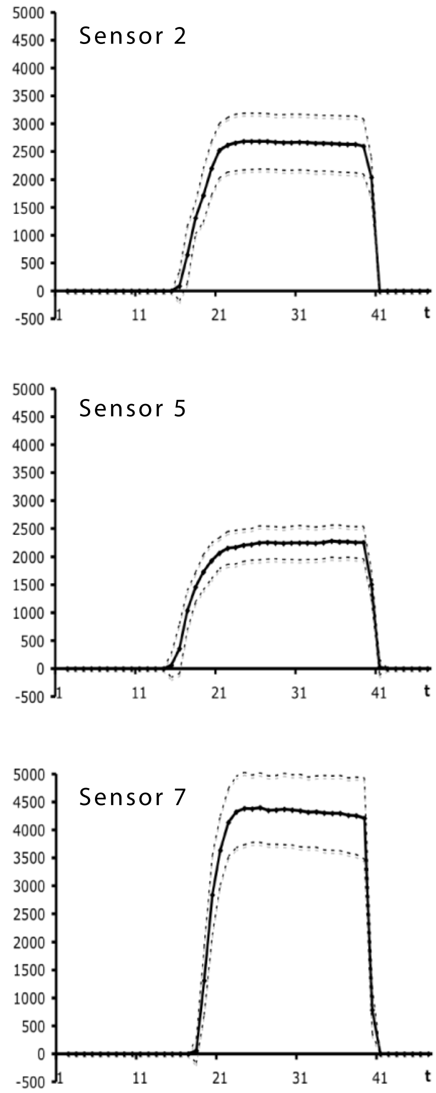

FIGURE 3: *Responses over time of the three sensors that reacted to the big ball 2. The other sensors did not react during the grasping of this object. The thick line is the average of 30 grasping tests. The thin dotted lines show the variance of the measurements.*

TABLE 1: *The objects tested by LUCS Haptic Hand I*

Object	Size	Hardness	Material	Sensors
Small Cube	Side 37 mm	Soft	Foam Rubber	S1
Big Cube	Side 55 mm	Soft	Foam Rubber	S7
Small Ball	Circumf. 130 mm	Rather Hard	Plastic	S1
Big Ball 1	Circumf. 196 mm	Medium Hardness	Rubber	S2, S5
Big Ball 2	Circumf. 224 mm	Rather Soft	Hard Foam Rubber	S2, S5, S6
Golf Ball	Circumf. 123 mm	Hard	Golf Ball	S1

and last longer with this cube, than in the case of the smaller one, i.e. the formation in the diagram is broader.

The small ball gave only a reaction on sensor 1, and the maximal strength of the signal was around 3500. There was a reaction of sensor 1 during the whole grasping movement, even when the thumb wasnt pushing against the boll. This is probably due to that the weight of the ball might have been applied directly to the sensor in the case of this object.

In the case of big ball 1 there were reactions of sensor 2 with a maximal signal of approximately 3500, and sensor 5 with a maximal signal of ap-proximately 4400. As the case was with the cubes, the signal curve starts earlier and lasts a little bit longer in this case than in the case of the small ball.

The big ball 2 gave reactions of sensor 2 with a maximal signal of approximately 2600, of sensor 5 with a maximal signal of approximately 2250, and of sensor 7 with a maximal signal of approximately 4400 (Fig. 3). The signal curves for sensor 2 and 5 are of approximately the same width as those for big ball 1, but the signals are weaker in this case, compared to the case of big ball 1.

Only sensor 1 reacted in the case of the golf ball with a maximal strength of the signal of approximately 3700. The width of the signal curve is approximately the same as in the case of the small ball, but the signal was a little bit stronger in this case.

The big cube, big ball 1 and big ball 2 could be trivially identified and distinguished from the other objects at looking at what sensors reacted (Table 1). The small cube, the small ball and the golf ball all only activated sensor 1 and a closer look at the signal is necessary to identify the objects (Fig. 4). The small ball could be easily distinguished by noting that for the this object, sensor 1 was active at all times - even before the grasp. This leaves the small cube and the golf ball which could be identified by noting that the reaction of sensor 1 was more than double for the golf ball. All objects could thus be categorized from the tactile signals received from the hand.

5 Discussion

By studying the diagrams for the different objects, that have been tested, one gets the impression that the signal patterns from LUCS haptic hand I, are differentiable according to size, shape, and hardness.

The difference in size becomes clear, since the signal patterns, for both balls and cubes, shows a signal that starts earlier, lasts longer, and stops a little later during the grasping movement in the case of a bigger object. In the case of balls, it also seems to be that more sensors are activated if the ball is bigger. Difference in form, i.e. whether the object is a ball or a cube, also possibly becomes clear from the signal patterns. In the diagrams one can see that the curves for the balls seems to have a steeper inclination in their left side, compared to the curves for the cubes.

The degree of hardness is also clear from the signal patterns. The height of the curve seems to indicate a harder material of the object. For example, this can be seen by comparing the signals for the sensor 2 and for the sensor 5 for the big ball 1 and the big ball 2. In these diagrams one can see that the curves are higher for big ball 1 than for big ball 2. This tendency can also be seen if the signals for sensor 1 for the small ball and for the golf ball are compared (Fig. 4), where the little harder golf ball also has a little higher curve. This needs further investigations, however, but indicates that it may be possible to generalize a learned recognition ability to novel objects.

The sensors seems to react somewhat asymmetrically, i.e. the sensors on the left finger (sensors 1, 2, 3) seems to react more than the sensors on the right fixed finger (sensors 4, 5, 6). This is probably due to that the angle between the fixed left finger and the thumb is slightly different from the angle between the right fixed finger and the thumb, because of small imperfections in

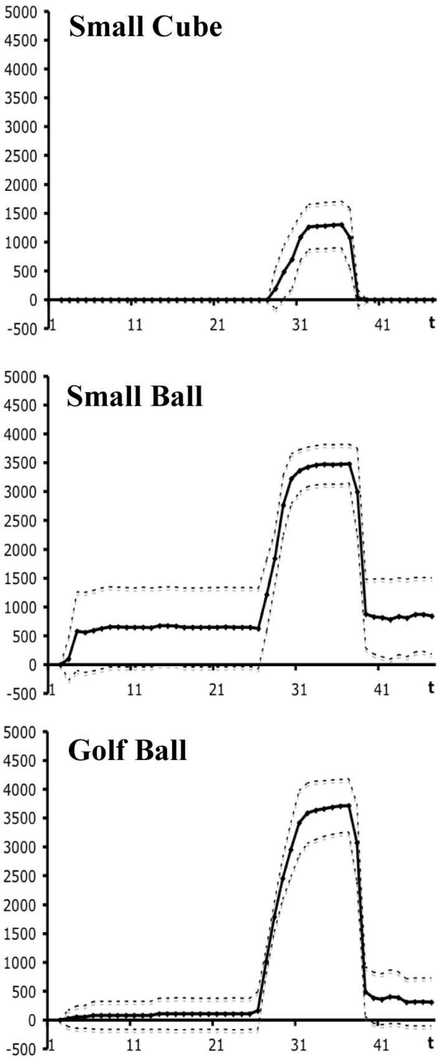

FIGURE 4: *The reaction of sensor 1 to the small cube, the small ball and the golf ball. The three objects could be distinguished based on this signal olone. The reaction for the small cube was much smaller than for the other objects. For the small ball, the sensor reacted all the time but not for the golf ball.*

the physical construction. The sensors and the tiny plastic plates mounted upon them might also be mounted with a slight asymmetry.

The results suggest that it should be possible to categorize the objects according to different properties of the signal patterns, i.e. properties like width, slope, height and so on of the diagrams. This should be more efficient and also more interesting compared to a categorization solely based on the raw data from the sensors. Implementing a mechanism that first extracts these properties from the raw data would make this possible.

Another lesson from the tests with LUCS Haptic Hand I is that the next robotic hand we builds should be equipped with jointed fingers that closes properly around the grasped object. This will allow a larger number of sensors to be activated during the grasping of an object, and it will thus use the whole capacity of the sensory system.

In the future, the signals from the hand will be used as input to a simulation of the first stages of somatosensory processing in the brain. The aim will be to develop a system that can actively explore an object with touch while simultaneously learning about its own sensory apparatus.

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