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Haptic Exploration of Objects

Kord Ehmcke
Cognitive Systems
Institute of Computer Science
Christian–Albrechts–Universität
Kiel, Germany
kord.ehmcke@web.de

Norbert Krüger
Computational Neuroscience
Department of Psychology
University of Stirling
Stirling, Scotland, UK
norbert@cn.stir.ac.uk

Abstract

In this paper, we describe the design of a haptic sensor and its use for haptic object exploration. The haptic sensor consists of hair sensors which detect touch and vibrations. At first we give a short description of the properties of the hair sensors and the predecessor of our haptic sensor (Schmidt et al., 2000). Differing from its predecessor, which was applied for grasping tasks, we focus on the haptic exploration of objects in terms of object shape and surface properties. For this new task, we needed to redesign the shape of the haptic sensor. By mounting the redesigned haptic sensor on a robot, we can then apply an exploration strategy which is based on a set of simple rules. Applying this strategy, the haptic sensor is able to explore objects autonomously. Finally, we give some examples of the automatic object exploration.

Keywords: haptic sensor, haptic exploration, hair sensors

1. Introduction

Human perception is based on different sensorial organs such as eyes, ears, or the olfactory system. Today, most of these organs can be imitated by artificial sensors (see, e.g., (Hierlemann et al., 2001, Riul Jr. et al., 2001, Hogan, 1985)). Vision is one of the most investigated sensorial modalities and a large part of the the human brain is devoted to vision. However, the human perceptive system reaches stable concepts because different senses are combined and it is important to investigate other sensorial modalities.

In this paper we describe the design of a haptic sensor for the exploration of objects. The haptic sensor consists of hair sensors which detect touch and vibrations. In section 2., we give a short description of the properties of the hair sensors and its predecessor (see figure 1). Differing from its predecessor, which was designed for grasping, we focus on the haptic exploration of objects. For this, we need to redesign the shape of the haptic sensor as explained in section 3.1. In combination with a robot, we apply an exploration strategy, which is based on a set of simple rules that are discussed in section 3.2. As demonstrated in section 3.3, by applying this strategy the haptic sensor is able to explore objects autonomously.

Figure 2: Hair sensor with fibers and metal base

2. Description of the Sensor

There are different robotic groups that deal with many kinds of haptic sensors. Recently Mark H. Lee (Lee, 2000) gave an overview of the situation in the field of tactile sensor technology. He points out that the design of reliable and stable sensors has been an obstacle for industrial applications. However, the potential field of application is considerable. Lee’s main thesis is, that different types of sensors, whether vision based or tactile, should be used where they have advantages. For example

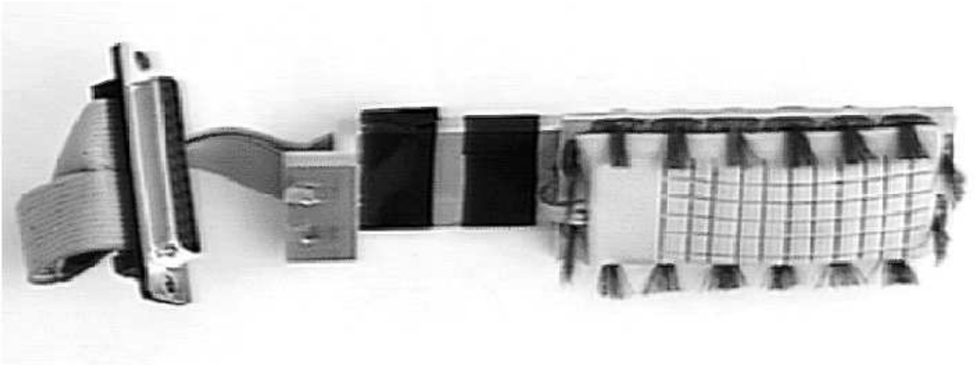

Figure 1: Jaw with hair-sensors and foil sensor from Schmidt, Maël and Würtz (Schmidt et al., 2000)

when dealing with sensitive objects such as fruits, haptic sensors give finer information than cameras may be able to give. Therefore, the design of efficient haptic sensors is crucial for their future application. One advantage of our kind of haptic sensor compared to many other sensors (see, e.g., (Butterfass, 2000, Cutkosky and Hyde, 1993, Jokusch et al., 1997, Rucci and Dario, 1993)) is that it is able to touch objects without moving or deforming them. This holds in general for the class of sensors hat are motivated by whiskers (see, e.g., (Wang and Will, 1978, Russel, 1985, Kaneko, 1998, Wijaja and Russel, 2002)). Whiskers are used by some animals such as cats and rats to explore their environment (see, e.g., (Beadle, 1977)) and to determine the contour of objects. For example, before eating its prey, the cat moves its nose several times over the prey to locate its head (Leyhausen, 1979)). The specific advantage of our device compared to other whisker based sensors is the use of hair resulting in a higher sensitivity than for example steel wire (see, e.g., (Wijaja and Russel, 2002)). Furthermore, our sensor is equipped with a large set of sensors. The form of the haptic devise on which the hair sensors are placed has been specifically designed for the task object exploration. This redundant and purpose–aimed representation allows for the reliable exploration of objects.

We started our work with a jaw from a two-hand robot gripper (Figure 1) which was developed in Bochum (Germany) by Schmidt, Maël and Würtz (Schmidt et al., 2000). The jaw is equipped with two kinds of sensors. It has hair sensors which are responsive to touch and vibrations. They are arranged around the second type of sensor on the jaw, a foil sensor for measuring pressure. These two types of sensors are used to support grasping processes. They make information available about positions of an object between the jaws and whether such an object is slipping. Here we are not so much interested in the grasping application but in object exploration by haptic sensors. For this we want to make use of the hair sensors of the grasping device (Schmidt et al., 2000).

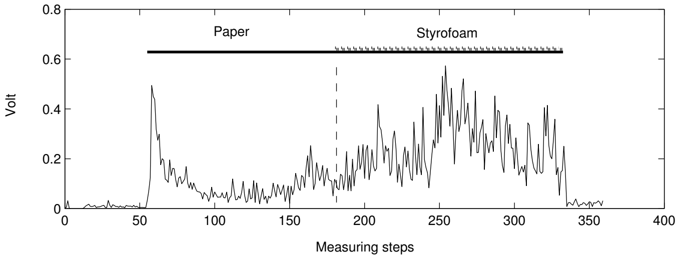

Figure 5: Haptic comparison of different surfaces. For the smooth paper the mean value for the high-pass filtered signal lies significantly above noise level. However, in case of the rougher Styrofoam the mean signal is even stronger.

The hair sensors are mainly fibers that are attached to a microphone membrane. Touching the fibers moves the membrane and this movement can be measured. Figure 2 shows such a hair sensor. A hair sensor supplies two types of signals. One signal, the main signal, can be used to detect touch. The other signal is the high-pass filtered main signal and can be used to detect vibrations. For more detailed information about the hair sensors we refer to (Ehmcke, 2002, Schmidt et al., 2000).

Since the hair sensors can be used to detect touch and vibrations, we use two test procedures to examine the characteristics of the hair sensors. Figure 3 shows the two basic sequences of these experiments. Pushing movements can be used to detect contact when the sensor is moved towards an object (see figure 3a). Sweeping Movements are used to move the sensor along an object (see figure 3b). In this case, the sensor can be used to detect, whether there is still contact between sensor and object.

We have created two test procedures corresponding to the two different kinds of signals. Figure 4 shows one example data set for each signal. Figure 4a) shows the main signal when performing a pushing movement.

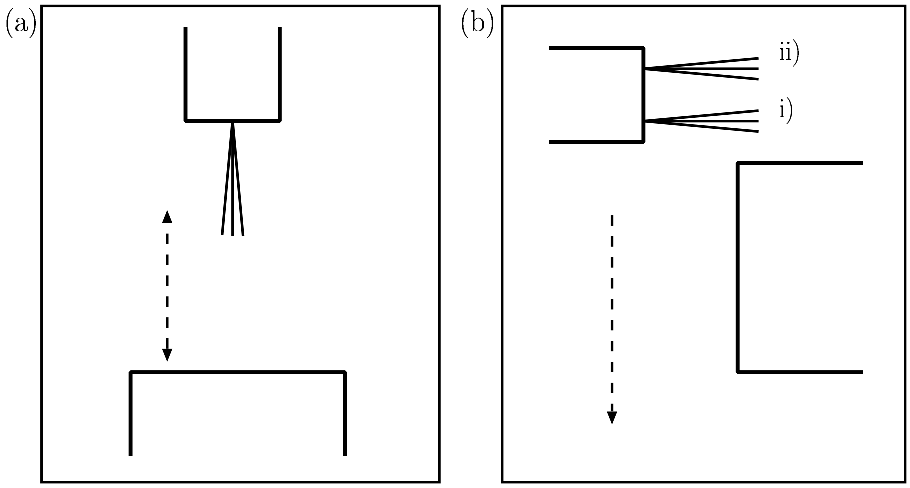

Figure 3: Test procedures for testing the detection of:(a) pushing movements(b) sweeping movements

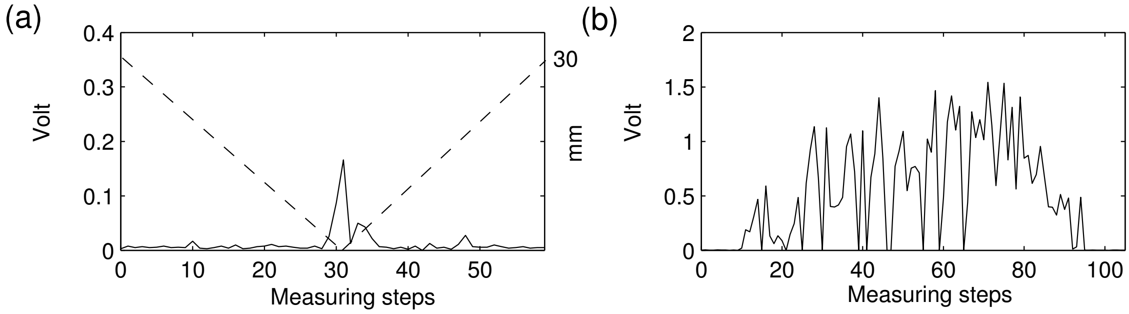

Figure 4: a) Main signal for a pushing movement corresponding to figure 3a. The contact with the object is clearly detected. b) High-pass signal during sweeping movement. During contact there is a clear (between 10 and 90 units) the signal is significantly above zero.

Figure 4b) shows the high-pass filtered signal during a sweeping movement. The hair sensors have to be moved to measure because they are dynamic sensors. We use small movement steps of 1 or 2 mm. This determines the basic measuring process. The robot arm with the haptic sensor is moved for one movement step and then the signals of the hair sensors are taken. Therefore, the unit on the x-axis of figure 4 and all other figures is the number of measuring steps. Note that the frequency of movements is so high that a continuous movement is observed.

The high-pass filtered signal can also be used to detect the roughness of a surface. Figure 5 shows the high-pass filtered signal of a hair sensor when swept over a changing surface. The first surface is paper which causes a signal of the sensor with amplitude less than 0.2 Volts. The second surface is Styrofoam, which is clearly rougher than paper. On this surface, the amplitude of the signal is significantly higher. This behavior enables us to distinguish surfaces by their roughness. As shown in (Ehmcke, 2002), we can get also other information about surfaces (e.g., we can detect repeating structures on surfaces).

3. Haptic Object Exploration

We now discuss the application of the hair sensor to the object exploration task.

3.1 Shape and Task

The haptic sensor (Schmidt et al., 2000) (see also figure 1) was developed to be used as a jaw for a two-hand gripper. The hair sensors support the grasping process, e.g. to detect whether an object between the jaws is slipping. Since our intention is to explore objects haptically we had to redesign the shape of the sensor.

Our goals were to support exploration by the shape of the sensor, flexible placement of the hair-sensors, better exploration results with redundancy of hair sensors, a small size of the sensor and some shorter hair sensors

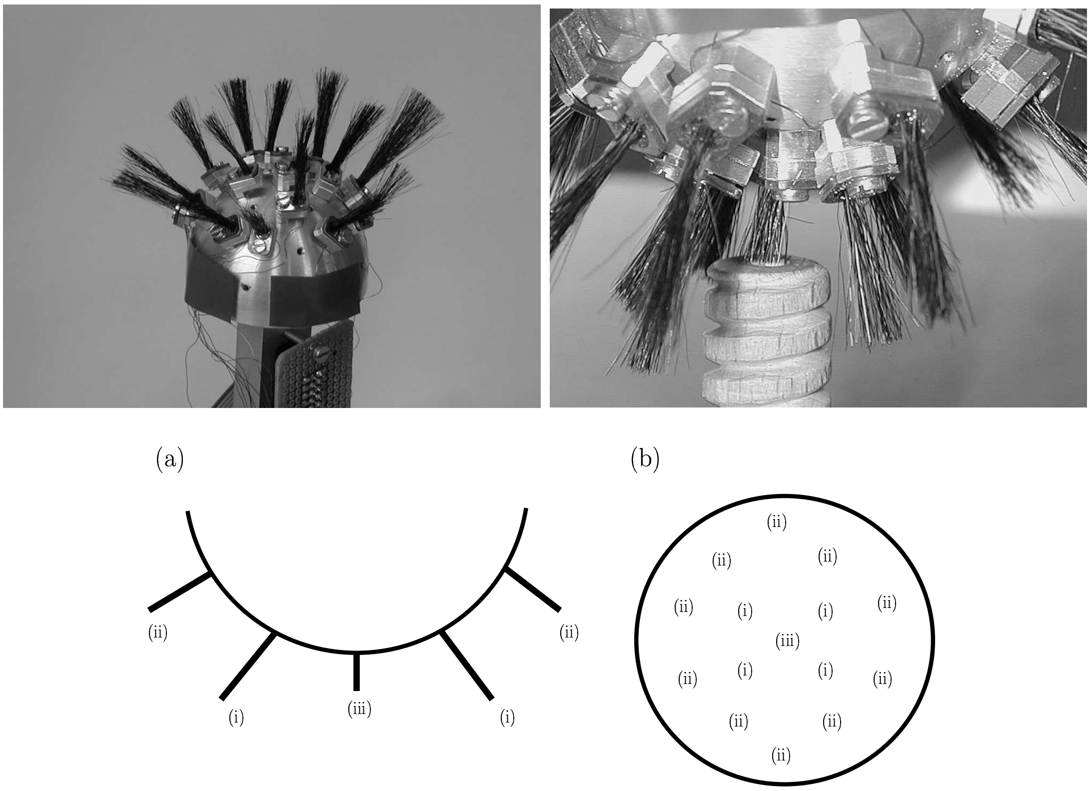
(a) (b)

Figure 6: **Top:** Left: Shape of the redesigned sensor for the haptic exploration of objects. Right: Shorter security sensors allow for keeping a minimal distance from the object. **Bottom:** Schematic description of the haptic sensor: (i) main sensors, (ii) side sensors, (iii) security sensors.

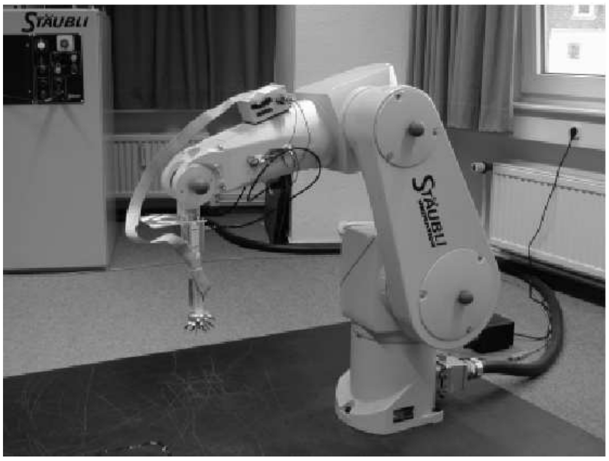

Figure 7: Robot arm with haptic sensor used for haptic object exploration.

to allow for keeping a minimal distance between sensor and object. The shorter sensors are called security sensors (they are used to keep a minimal distance to the object). Figure 6 shows the new sensor and a zoom on a security sensor figure 6 (top). Figure 6 (bottom) shows a schematic description indicating the different sensor types. It is a metal hemisphere with holes where hair sensors are screwed in. This design makes it possible to detect objects in almost all directions. The modular attachment of hair sensor enables a flexible change of hair sensors on the hemisphere. We also have more than one hair sensor in each main direction. This redundancy makes the sensors more reliable. In addition, this design allows for sufficient space for shorter hair sensors, the security sensors between the normal hair sensors (see figure 6 (bottom)).

3.2 Strategy

To explore objects, we mount the haptic sensor on a robot arm (see figure 7) and apply a set of simple rules. Figure 8 shows the rule system we used for automatic exploration. The main idea behind these rules is to give a direction and a distance to the computer system and then let it find its way autonomously in that direction applying the rules. The rules work in a way, that the sensor is moved by a robot arm depending on the contact situation of the hair sensors. For example, if a hair sensor in the given direction has contact to an object, then the sensor has to be moved up to pass over this object. Direction in (x, y) and distance of the movement

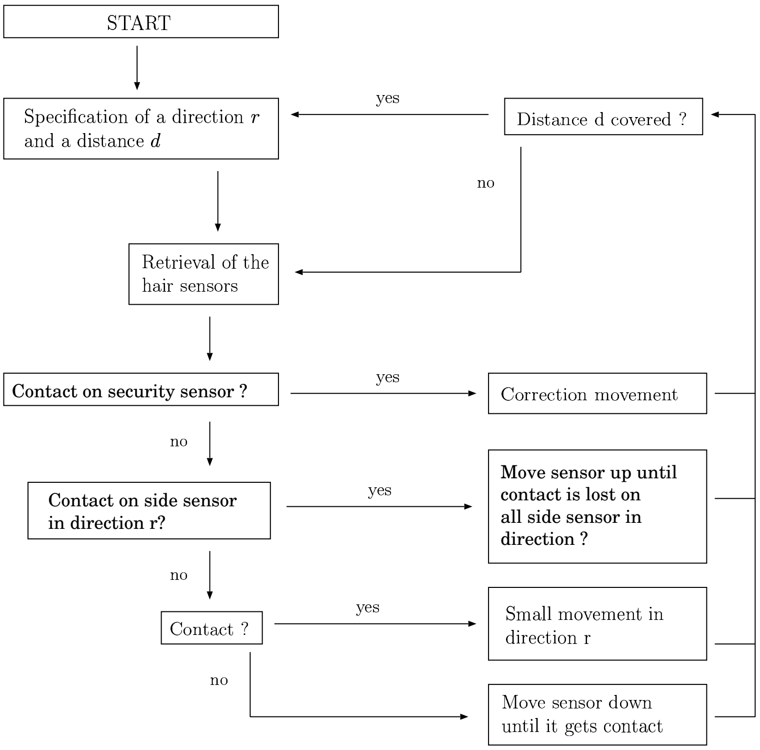

Figure 8: Exploration rules

are supposed to be given externally. Then a movement of the robot arm according to the given direction is performed that keeps permanent contact with the object.

The rules consist of set of action perception cycles (see figure 8). To start the system, a movement downwards is performed until contact with the object takes places. Then in a first cycle, it is checked whether there is contact to the safety sensors. If that is the case an upwards movement is performed until no contact to the safety sensors occurs anymore. In a second cycle, contact to the side sensors is checked to see whether a motion to the side is possible. If there is contact to the side sensors the robot arm moves upwards until contact is lost. Then, if contact to the main sensors is still existent, a movement step in the given direction takes place. If there is no contact to the main sensor, a downwards motion is performed, before the movement in the given direction takes place. As shown in the next subsection, these simple rules lead to a stable exploration of objects.

3.3 Experiments

Using the rules explained above we made some experiments to prove, that the system of haptic sensor, robot arm and rules can automatically explore objects. Figure 9 shows the result of one experiment with the model of a house (ca. 30 cm long and 20 cm wide). The two views show the projected data in 3D space. The shape of the house can be recognized very well.

In general we can state that although the information delivered by the hair sensors shows significant noise patterns (see figure 4 and 5), the haptic exploration shows a rather stable performance. Thus is mainly grounded in the large number of sensors and their tasks adapted design and constellation. In (Ehmcke, 2002) we have performed more tests with different objects that demonstrate the stability of our approach.

4. Summary

We have introduced a new kind of haptic sensor. One particular quality of this sensor is its ability to touch objects without actually moving or deforming them. In combination with a robot arm, we could use this sensor for an autonomous exploration of objects. To apply the sensor to the object exploration task, a redesign of the sensor was necessary. This amplifies the dependency of shape and task. Finally, we could show that we can distinguish different kinds of roughness of surfaces by our sensor.

In the future, we especially intend to use this sensor in combination with Vision. Touch and vision have complementary strengths and weaknesses. For example, for artificial vision it is difficult to extract 3D information at homogeneous surfaces while our haptic sensor can support vision with such information. Also haptic textures

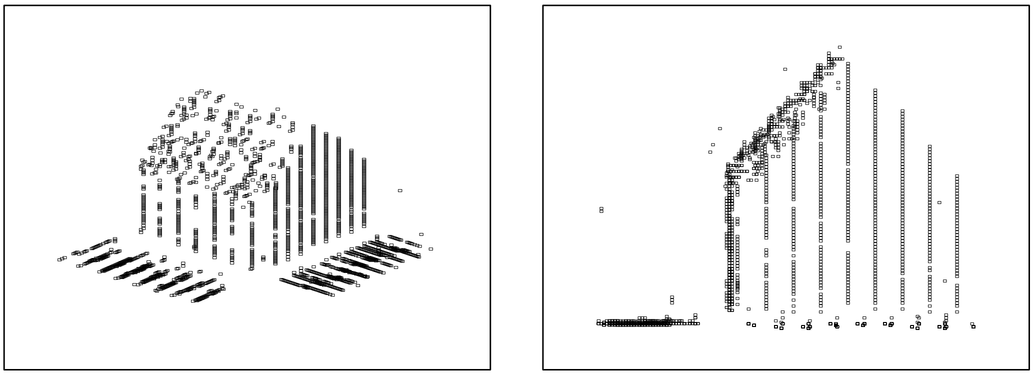

Figure 9: Two views of the projected data

can be recognized and interdependencies between visual attributes and haptic attributes can be acquired.

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