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Object Exploration using Whisker Sensors

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Abstract

This paper describes the progress of a project to locate, recognize and manipulate objects using information from whisker sensors. Object surface information is gathered by measuring the angle of deflection of a rigid whisker as it slides over the object surface. In order to successfully reconstruct the surface shape of an object, the whisker tip has to be in contact with the object. Ambiguous information is produced when the contact position is along the whisker length. We have developed a novel sensing algorithm that solves this problem. Using the algorithm it is possible to determine whether the contact position is at the whisker tip or along the whisker length simply by rotating the mobile robot on the spot. We present the design of the mobile robot and the whisker sensor together with some practical results. We also show how to estimate the contact position when the contact is along the whisker length. A single whisker sensor is mounted on a mobile robot to explore the objects it touches. Experimental results show that the whisker sensor is capable of gathering the surface shape information of an object, and the test algorithm can be used to confirm the contact as either at the tip or along the whisker length.

1 Introduction

One of the possible requirements for an autonomous mobile robot is the ability to detect, explore, and recognize objects in the environment. To carry out these tasks, a mobile robot must be equipped with some sensors. Vision would be a popular choice however these sensors may be required to work under a wide variety of environmental conditions, such as in darkness, in very dirty or dusty situations, in foggy conditions or even underwater. Tactile sensing is a good choice because the information provided directly represents the object properties being measured. Nature gives us good hints about the use of whisker sensors on some animals, such as cats and rats. It seems that these animals can explore their environment and extract information about object properties by using their whisker systems. To get information about the object, the whisker sensors have to be in physical contact with the object. This means that for the whiskers to work, they have to be carried by some sort of mobility device to bring the whiskers in physical contact with the object. The exception would be if the object is actively move toward the whiskers. We have developed and mounted a whisker sensor on a mobile robot which is able to reconstruct the surface shape of objects in its environment. The data gathered from this experiment will be used for object recognition in a later stage of the project.

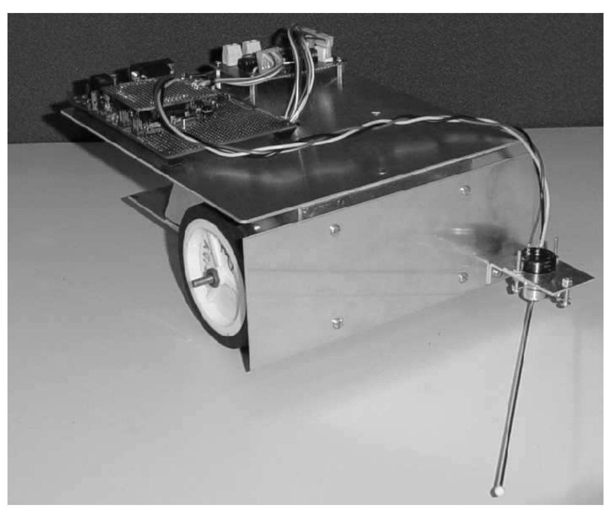

Figure 1: A whisker sensor based mobile robot.

1.1 Biological Inspirations

Some animals like cats and rats use whiskers or vibrissae to help them negotiate their enviroment. For them, whiskers are important supplements to vision. Since they extend sideways beyond the head and can be fanned out, they help a cat decide whether a small opening offers enough clearance for its body. They can also detect the tiny variations in air currents that are deflected from solid objects. These allow cats to sense the presence of objects without touch them. They also help cats to move around in the dark without bumping into things [Beadle, 1977]. Whiskers can also be used to detect prey that are so close to their nose that their eyes can't bring it into focus. A blindfolded cat can locate a mouse very quickly and, as soon as it touches it with its whiskers, grasp it with a precise nape bite within one-tenth of a second. When the cat springs on its prey, its whiskers protrude as far forward as possible and obviously help to keep a check on the prey's movements after it has been seized. Small prey, such as mice, are practically enveloped by them. Cats also use their whiskers to detect the contour of the prey's body to determine the head location. Before begining to eat, the cat moves its nose several times over the prey. This allows it to feel the direction of the hair of its prey and to locate its head [Leyhausen, 1979].

Hartmann shows that rats use their whiskers to explore and discriminate objects. During free exploration, the rat rhythmically moves its head to place its small (micro) vibrissae on the surfaces it is exploring. These periodic "microvibrissal placements" are temporally synchronized with the whisking movements of the large (macro) vibrissae. It was also found that rats may sometimes use their micro and macro vibrissae consecutively, instead of simultaneously [Hartmann, 2001]. It seems that these whisking movements play a very important role during object exploration. In this research we incorporate similar movements into our novel sensing algorithm to detect the contact position.

1.2 Related Works

A simple whisker sensor can be made from a length of a flexible wire anchored at one end. When the free end touches an object, the wire will bend and this can be detected by a piezoelectric element or a simple switch [Russell, 1984]. This kind of whisker sensor has been described by Wang and Will [Wang and Will, 1978]. Their whisker was mounted on a pneumatic actuator so that the whisker could be retracted for protection when heavy lifting was performed. A single whisker switch can be used to locate and recognize an object, but it is very slow because after each reading the whisker has to be re-oriented to measure another contact point at a different position.

The use of whisker sensors or antennae-like sensors has also been reported in mobile robots. Simple whisker sensors can be mounted on mobile robots to provide warning of obstacles. Long antenna-like whisker sensors were mounted on the SRI mobile robot Shakey [McKerrow, 1991] and on Rodney Brook's six-legged robot insects [Brooks, 1989]. Hirose *et al.* used curved whiskers under the feet of the four-legged robot TITAN III to detect both ground proximity and obstacles [Hirose *et al.*, 1985]. These whiskers were made from shape-memory alloy because the high elasticity of this material allows it to tolerate a relatively large amount of bending without suffering permanent deformation. Similarly shaped whiskers have also been considered for the legs of the Ohio State University active suspension vehicle [Schiebel *et al.*, 1986]. An articulated whisker probe has been described by Russell [Russell, 1985]. This whisker was actuated by horizontal and vertical voice-coil actuators. The probe used a switch type impact sensor to detect contact with an object. The sensor was able to construct outline images of objects.

A passively articulated whisker sensor was developed by Russell [Russell, 1992]. He used a curved rigid fibre composite whisker with the root mounted on a potentiometer coupled with a light spring. The potentiometer measured the angle of rotation when the whisker tip touched an object. Similar whiskers were also developed by Jung and Zelinsky, and were succesfully implemented on their mobile robot for high speed and close wall following [Jung and Zelinsky, 1996].

Tsujimura and Yabuta described a sensor consisting of a force/torque sensor mounted at the root of a flexible insensitive probe [Tsujimura and Yabuta, 1992]. The contact point along the probe was estimated using force and moment data measured by the force/torque sensor. Their shape detection experiments were carried out using a robot manipulator with the probe equipped with a force/torque sensor mounted on it. Kaneko *et al.* eliminated the force sensor and used only four components for their system, an insensitive flexible beam, a position sensor, a torque sensor and an actuator. They called their sensor an active antenna. The sensor was able to localize the contact position along the beam by using active motion. When additional angular displacement is induced in the beam after it makes contact with an object, it is possible to estimate the contact position along the beam using torque information [Kaneko, 1998]. They have also developed a 3D version of the active antenna, which consist of an insensitive flexible beam, two actuators to move the beam in 3D space, two position sensors to measure the angular displacements, and a two axis moment sensor [Kaneko *et al.*, 1995]. Another method used by them is the dynamic active antenna. By analizing the natural frequencies of the beam when it strikes an object, they were able to estimate the contact position [Ueno *et al.*, 1998].

2 Whisker Sensor Design

Cat and rat whiskers are stiff hairs which act like levers, pivoting at the bulbous root which is rich in sensory nerves. Unlike the insect antenna which is rich with sensory nerves along the antenna. This project was motivated by observation of cat and rat whiskers. Using an insensitive probe as the whisker with the sensor mounted at the root gives advantages of simpler and cheaper design. Because the whisker will often be touching the object, it will be easily broken if it is made from fragile materials. Figure 2 shows a schematic view

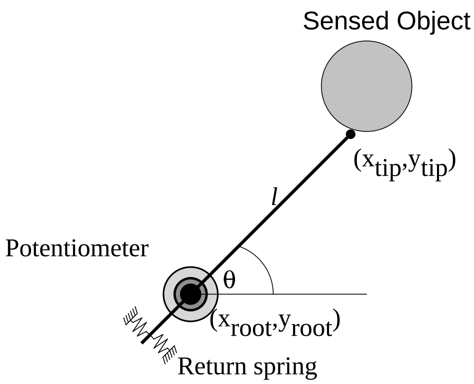

Figure 2: A schematic view of the whisker sensor.

of the whisker sensor. It consists of a straight rigid wire mounted on a low friction potentiometer together with return springs. We used a 20cm length of 1.6mm diameter steel welding wire as the whisker. A 4mm diameter plastic ball was attached to the tip of the whisker to improve its ability to slide over a range of surfaces. The whisker is free to rotate about one axis to allow it to track the surface of the external object. The whisker angle of rotation θ is measured by the potentiometer and the spring returns the whisker to its initial orientation when it is not touching an external object.

Using the whisker sensor coordinate system, the whisker tip coordinate is given by:

$$(x_{tip}, y_{tip}) = (x_{root} + l\cos\theta, y_{root} + l\sin\theta) \quad (1)$$

In use, the whisker is mounted on a mobile robot. When the whisker tip touches an external object, we can obtain the point of contact by using Eq. (1).

Figure 3 shows the coordinate system of the mobile robot carrying a whisker sensor. W represent the world coordinate system, M the mobile robot, R the whisker root and T the whisker tip.

We can calculate the tip position in the world coordinate system using the P_{WT} transformation shown in Eq. (2).

$$P_{WT} = P_{WM} + P_{MR} + P_{RT} \quad (2)$$

Using the whisker angle and the mobile robot position and orientation, we can find the position of points

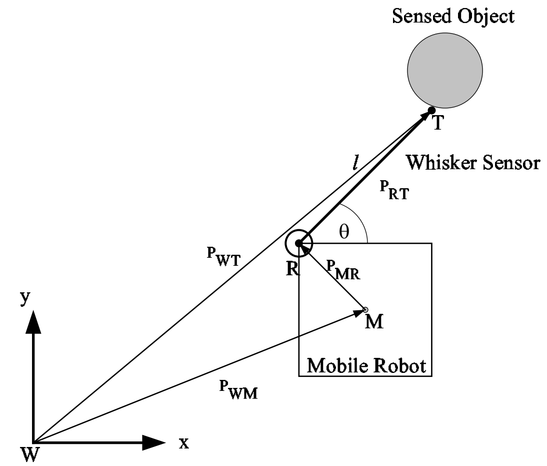

Figure 3: The coordinate system for the whisker sensor based mobile robot.

on the surface of an object with respect to a world coordinate. As the robot moves, the whisker tip will slide over the surface of the object. This gives a set of surface points, that can be used to reconstruct the surface shape of the object.

3 System Design

The mobile robot used in this experiment is a differential steering type using two stepper motors to drive the left and right wheels. The mobile robot uses specially designed wheels to improve the accuracy of the robot positioning. Accurate positioning is important because points on the surface of an object will be measured with the robot in different positions. For this reason, it is essential that the movement of the robot is accurately controlled. A Motorola 68HC12 microcontroller is used to control the stepper motors and read the whisker sensors via an in-built A/D converter. Two PWM outputs are reserved for future use to control an arm and gripper to manipulate objects.

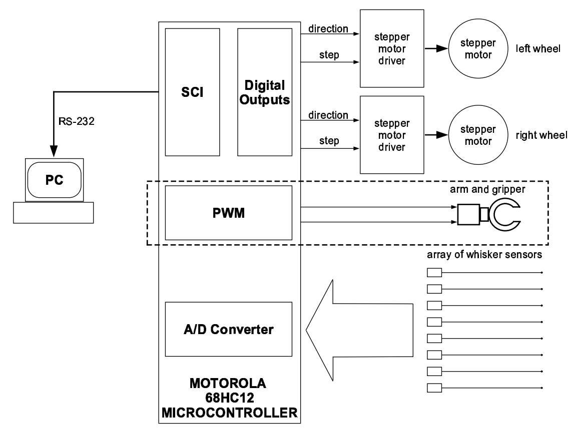

Figure 4: The system block diagram.

A PC communicates with the microcontroller through a serial RS-232 line. The mobile robot is a slave, it is only doing what the PC commands it to do. It can be commanded to move both wheels a specified number of steps and direction, and to send sensor readings to the PC. Figure 4 shows a block diagram of the system used in this project.

4 Tip Test Algorithm

If the contact point is at the whisker tip then the information can be used directly to reconstruct the surface shape of the object. There will be an ambiguity in the interpretation of the sensor data if the contact point is along the whisker length (figure 5). Therefore, we need more information to reconstruct the object surface. First, we have to know the position of the contact point, whether at the tip or along the whisker length.

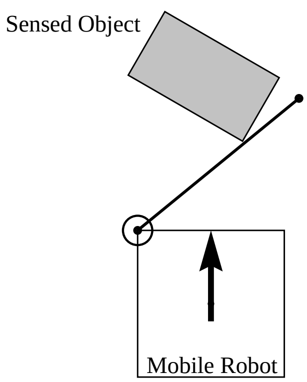

Figure 5: Ambiguous condition when the contact point is along the whisker length.

As mentioned before in the previous work by Russell [Russell, 1992], it is very difficult to make a switch which responses reliably to a gentle pressure. His solution, to used a piezoelectric switch, was found to be difficult to use because it needs extra circuitry and wiring. It was also found that the switch was very fragile.

In this project a novel test algorithm was developed which utilizes the robot movement to check whether the contact is at the tip or not. Information from tip contact will be recorded directly and used to reconstruct the surface shape of the object. Other information will be recorded for future use to estimate the contact position along the length of the whisker.

Figure 6 and figure 7 show how the algorithm works. We need two measurements that represent two points of contact T_1 and T_2. In the testing phase, we rotate the robot on the spot through an angle δ so the whisker root will be at the point R_3 which is the intersection of two circles, circle $C_1(centre = T_1$ and $radius = l)$ and circle $C_2(centre = M_2$ and $radius = d)$, where d is the distance M_2R_2.

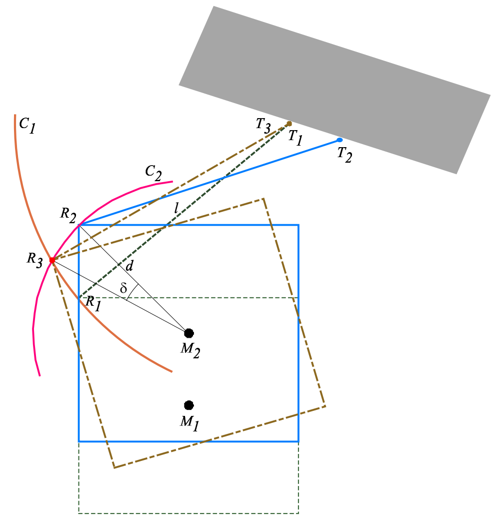

Figure 6: Tip test algorithm for contact at the tip.

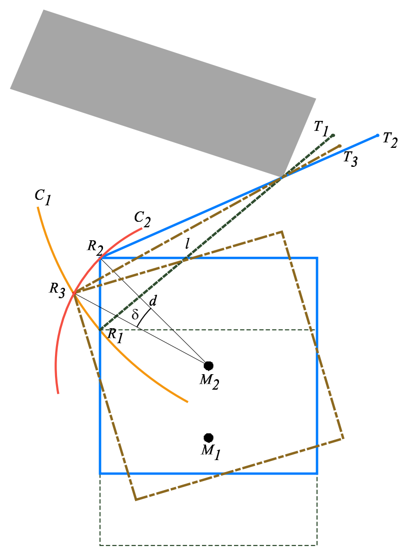

Figure 7: Tip test algorithm for contact along the whisker length.

If the contact point is at the tip, we will obtain the result $T_3 = T_1$ (figure 6) and the tip position T_1 is recorded as valid data.

If the contact point is along the whisker length, we will obtain $T_3 \neq T_1$ (figure 7). To estimate the contact position along the whisker length, we solve the line intersection formed by the whisker root-tip connection line at different positions. The first point is the intersection of line R_1T_1 and line R_2T_2, and the second point the intersection of line R_2T_2 and line R_3T_3. If both intersection points are at the same position (coordinate), we can assume that the contact point is the object edge. But if the intersection points occur at different positions, we can assume that the points are surface points of some curved object. With more readings, we can estimate the radius and the centre of the object curvature.

5 Results

Initial experiments were carried out using a single whisker sensor mounted on the mobile robot. The robot was controlled using a 68HC12 Motorola microcontroller communicating with a PC. The output of the whisker potentiometer was read by the A/D converter on the 68HC12 and sent to the PC to be processed.

Before contact with an external object, the angle of the whisker was set by the springs to be 45 degrees. The PC commanded the mobile robot to move forward in 5mm increments while the whisker angle was monitored. A change in this angle indicated contact and initiated recording of the angle θ together with the robot position and orientation. After several readings, the test-algorithm was performed to confirm that the data were generated by tip contact. If the data resulted from tip contact, they were used to reconstruct the surface shape of the external object.

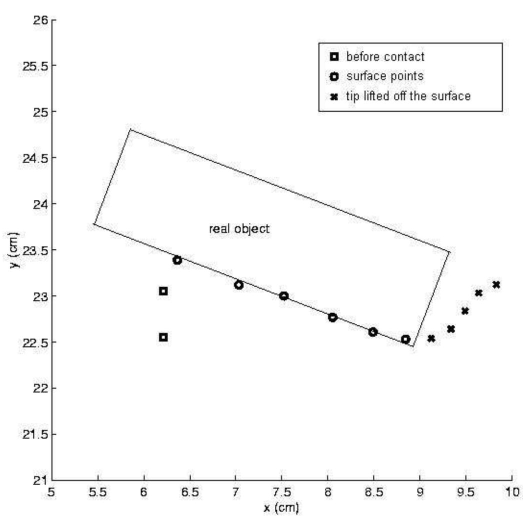

Figure 8: Result for a block shaped object.

Figure 8 shows the output of the sensor for a block shaped object. The samples marked with a square were recorded before the whisker touch the surface of the object. Valid samples are marked with a circle and samples marked with a cross are invalid data occuring when the whisker tip lifted off the surface (contact point along the whisker length). Figure 9 shows the output of the sensor for a cylindrical object. Both results showed the capability of the whisker sensor to reconstruct the surface shape of an object. A complete reconstruction of the object shape can be done by approaching the object from different directions.

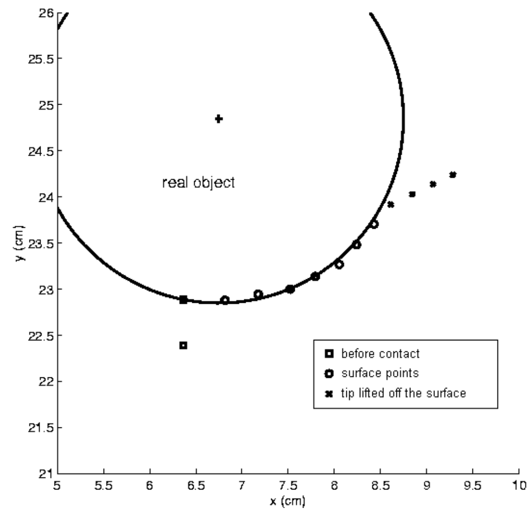

Figure 9: Result for a cylindrical object.

6 Conclusion and Future Works

A whisker sensor has been constructed and mounted on a mobile robot to perform object exploration. The whisker is attached to a potentiometer to measured the angle of rotation when it touches an object.

In the current stage of the project, only information gathered from tip contact is used to reconstruct the surface shape of the object. We have developed a novel sensing algorithm to test whether the contact position is at the tip of the whisker or along the whisker length. That technique does not require additional sensors.

Further work is required to mount an array of whisker sensors on the mobile robot to gather 3D information of the surface shape of an object. An algorithm will then be developed for recognizing the shape and orientation of the object. This information can then be used to manipulate the object. In the future, the robot will navigate the environment autonomously to find certain objects to be picked up.

It is hoped that this project will demonstrate that arrays of whisker sensors can be used as practical robot sensors in environments that would not be suitable for more conventional visual or ultrasonic sensors.

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