Whisking: An Unexplored Sensory Modality

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Abstract

Whiskers are widespread in the animal kingdom because they play an essential role in adaptive behavior. In spite of the enormous potential of whiskers, they have yet to be systematically investigated and exploited by roboticists. In this work, we present a first series of experiments with prototype artificial whiskers that have been developed in our laboratory. These experiments have been inspired by neuroscience research on real rats. The experiments provide the foundation for future work including active sensing, whisker arrays, and cross-modal integration.

1 Introduction

Whisker signals can be exploited to deliver a wide range of information about the environment such as texture, distance, shape, and orientation. Thus, there is a potential overlap with other sensory modalities, for example vision, which yields precise spatial information. In spite of the enormous potential of whiskers, they have been up to now almost completely neglected by the robotics community: For the better part, the research has investigated sensors based mostly on binary touch devices, called whiskers, tactile whiskers (Russell, 1992), or active antennae used for distance measurements (Kaneko et al., 1998). However, natural whisker systems - according to our hypothesis - yield much richer information.

The rodent somatosensory system is characterized by a prominent representation of their mystacial vibrissae (called whiskers). Though rats and mice strongly rely on visual and olfactory cues, their somatosensory system (here: their whiskers) is an important and accurate sensory modality. Rats are able to distinguish sandpaper surfaces purely on the basis of cues from the whiskers (Guic-Robles et al., 1989). It is even suggested that the accuracy of rat whiskers is comparable to that of primates finger tips (Carvell and Simons, 1990).

In this work, we present a prototype of a realistic artificial whisker sensor, which returns signals with properties, that can potentially be processed in a way similar to the rat somatosensory system. The artificial whisker system consists of a whisker-shaped material probe, which was chosen among a small set of materials such as plastic, human hair, and real rat whiskers.

2 Artificial Whisker and Experimental Apparatus

The core element of our sensor is a standard off-the-shelf *electret* microphone capsule (see figure 1a), which is a particular type of electrostatic sound sensor. In order to build the actual *whisker sensor*, we glue a small piece of a whisker-shaped (straight or curved thin and circular) rod of whatever material we wish to employ on the diaphragm of the microphone with a relatively hard glue (vanilla *cyanoacrilic super-glue*). Upon contact with an object, the whisker-shaped rod transmits the resulting contact force to the plate capacitor, where a small, but detectable change of its plate distance is induced.

The experimental setup consists of a plastic cylinder on which different types of material samples can be attached. It is possible to have samples with smoothly or roughly textured surfaces (e.g., plastic, paper or sandpaper). The cylinder is placed on a $12V$ DC-motor, whose turning speed is controlled by means of a microcontroller unit, connected via a serial cable to a host computer. The distance between the plastic cylinder and the base of the whisker sensor can be adjusted (see figure 1b).

3 Analysis Methods

The analysis of the time series data collected for this paper have been performed in the frequency domain. We are interested in basic oscillations, or fundamental modes, that are the result of the interaction of sensing device and environment. The discrete Fourier transform (DFT) of N data points of a sequence of samples x_k is defined as $X_n = A_n + iB_n = \sum_{k=0}^{N-1} x_k e^{-2\pi ikn/N}$. The power spectral density (PSD) describes how the power (or variance) of a time series is distributed with frequency. In our case, we make use of a popular nonparametric PSD scheme developed by Welch (Welch, 1967).

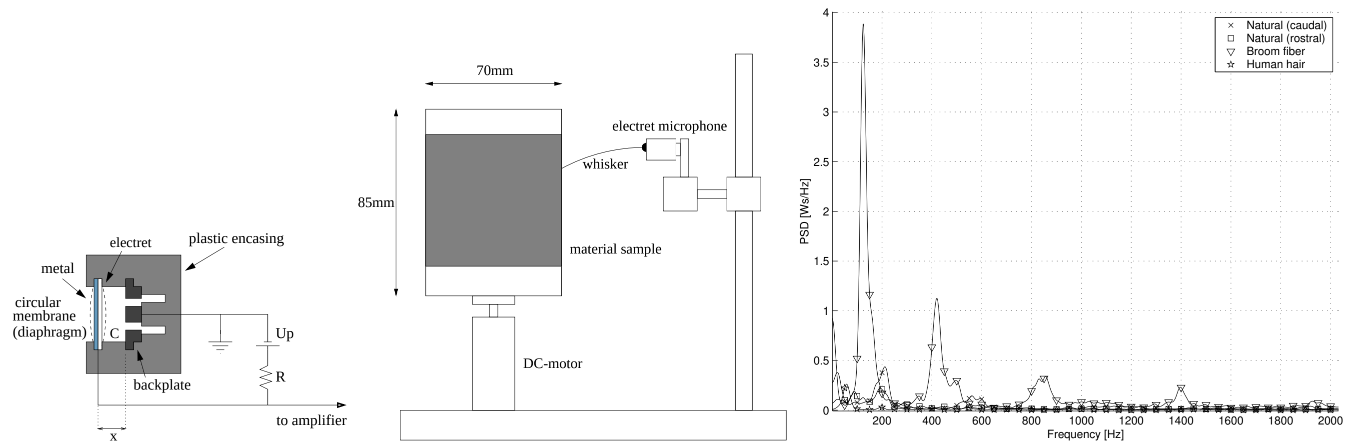

Figure 1: a) Basic schematic of an electret microphone. The deflection of the circular membrane, in response to a change of pressure, is measured by the change of capacitance. b) Schematic drawing of the experimental apparatus used to perform the experiments. c) Power spectral density (PSD) of four different type of whiskers.

4 Results of First Experiments

For a complete and thorough understanding of this sensing device, many parameters have to be taken into account. These include length and mechanical properties of the whisker (elasticity, stiffness, moment of inertia), material characteristics of the glue, location where the whisker is glued on the diaphragm, amplifier gain, radius of curvature of the whisker, and so forth. The goal of the initial set of experiments was to get a feel for the extent to which the material properties of the whisker are responsible for the characteristics of the sensory signal. Four different whiskers have been built and tested, one made of a small hair-shaped piece of polyvinyl (plastic) of length $l = 38mm$, a human hair ($l = 37mm$), and two types of rat whiskers ($caudal$, $l = 51mm$, and $rostral$, $l = 35mm$). Figure 1c displays the PSD of the time series of the different whiskers over a $1s$ time interval. Stiffness seems to play a major role. For the polyvinyl whisker, the ratio of the amplitude of the 1^{st} peak and the amplitude of the 2^{nd} peak and the one of the 2^{nd} and the 3^{rd} peak are bigger than the same ratios for the other three whiskers. Further experiments have been performed to categorize different cylinder surfaces made of sandpaper of different roughness (not shown here).

5 Conclusions

We have built an artificial whisker sensor consisting of an electret microphone on which we have glued a small whisker made of different materials. By performing palpation experiments with a rotating cylinder, we have shown that the artificial whisker sensor is producing complex data, which depend on various parameters. Comparing different materials for the whisker, we found out that a real rat whisker attached to our sensory system produces more clear and stable data. We assume that the natural whiskers have good damping properties compared with the artificial materials. Another interesting aspect of our prototype is, that by acoustically listening to the amplified output of the raw whisker sensor data, a human observer was able to distinguish different surfaces explored by the whisker. It will need further investigation to take all possible parameters into account.

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