Designing Whisker Sensors for Noisy Environments

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***Abstract*—Whiskers represent a method for robots to get detailed tactile information about an environment with minimal risks of causing damage. During whisker object contact, whiskers bend, transmitting a signal to the whisker's base. Since the sensors are not light-dependent and work best up close, they work succeed when vision-based sensors are most likely to fail. However, the benefits of whisker sensors are still limited to lab environments, as separating useful and noisy sensor signals is much harder in the unstructured world. Here we present a sensor that addresses signal noise by identifying airflow or inertial sensing signals. This sensor is also highly reconfigurable, making it an accessible testbed for future differing whisker arrays. A separate sensor can also identify contact on rigid surfaces and compliant surfaces. As tactile information from engineered whisker sensors becomes more informative and reliable, robotic platforms can make more informed choices about their interaction with the world.**

Tactile exploration of space in uncontrolled environments requires sensors equipped for contact at varying forces and speeds. However, current electronics do not exist which are robust to large contact forces and sensitive to small contact forces. Furthermore, it is not just the sensor that risks breakage; damage to the environment is an equally strong concern—grasping, moving, and contacting objects in the environment all present opportunities for accidental damage. One effective way to decrease the risk to the sensor is to separate the sensor and the contact surface, which has been demonstrated in tactile skin sensors [1, 11, 10] and engineered whisker sensors [2, 5, 8, 9, 6].

While tactile skins are the best choice for safely discerning tactile information in a grasping task or on an end effector [1, 10, 11], when tactility mapping unknown 3-d spaces, engineered whisker sensors are more efficient and safer. The whiskers length increases the pace of determining contact points and noncontact points in 3-d space, especially when they are rotated, whisked, through a space. Mirroring their biological counterpart [7], engineered whisker sensors keep their transduction method at or below the whisker's base [2, 5, 8, 9, 6]. This separation allows the whisker's length to undergo contact without damaging the electronics. In addition, many of the engineered whiskers are compliant and bend during contact [2, 8]. The compliance of the whisker means whisking can occur at high speeds with minimal concern that unpredicted contact will exert large forces on the environment or the sensor.

When whisker sensors are tested in lab environments they can gather high-density shape information [9, 6], map 3-d spaces [8, 2], and classify objects [5]. However, achieving these feats in uncontrolled environments with multiple objects, non-contact stimuli sources, and moving/compliant objects is still challenging. Our research on whiskers sensors which

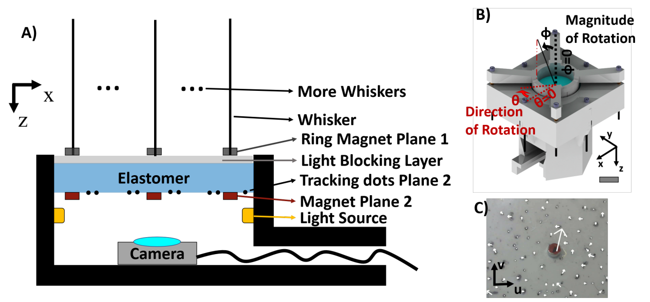

Fig. 1. A diagram of the WhiskSight sensor. Whiskers (rigid carbon fiber rods) are attached to an elastomer membrane suspended above a camera. The attachment is magnetic, using a disc magnet attached to the whisker on top of the membrane and another disc magnet below the membrane. B) The camera captures the motion of the bottom of the magnet in the camera image and uses it to calculate the rigid whiskers' magnitude and direction of rotation, ϕ and θ in spherical coordinates. C) During rotation only the bottom of the magnet moves. The arrows show motion of a tracked point in the camera image at 10x scale. This figure is reproduced from [4]

overcome these challenges has produced two designs. The first sensor, the WhiskSight sensor [4], uses magnetic attachments for six rigid whiskers to create a modular testing platform to investigate how the placement of whiskers affects sensed information (Fig 1A). The sensor can also discern contact signals from signals caused by airflow or body inertia stimuli removing one source of error. The second sensor uses a compliant whisker to the suspended setup to differentiate between whisker contact on compliant and non-compliant surfaces, minimizing another source of environmental introduced error (Fig 2).

Arrays of whiskers in rats are rows and columns of whiskers with different lengths, curvatures, and thicknesses totaling up to 25 whiskers per side of the face [7]. The density of the whiskers and the whisking motion allow rats to identify contact areas and noncontact areas close together, map small spaces and make determinations about food. However, no studies have quantified the relative effectiveness of different configurations of heterogenous whiskers in an array for robotic applications. Testing many different whisker arrangements may provide insight but rearranging many individual sensors introduces the annoyances of managing the sensors' connections (power and sensing wires) and increases the number of components that could break.

By combining the camera transduction method shown in other sensors [11, 10, 6] with magnetically detachable whiskers, the WhiskSight sensor facilitates future studies into the effect of array shapes on information gain [4]. By marking the magnets of each of the whiskers red in the camera image, we minimized the researchers' work as researchers can change

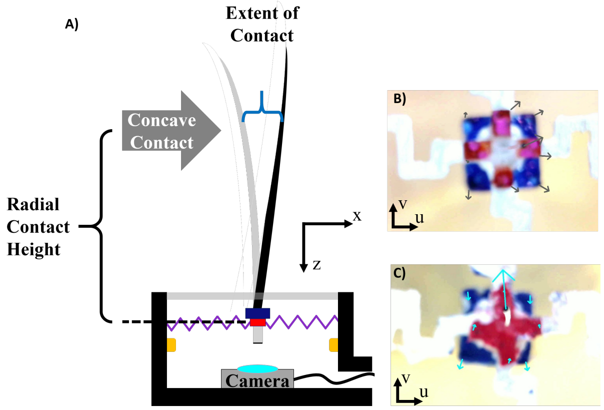

Fig. 2. A schematic of the compliant whisker sensor: A) A 3-d contact point on a whisker comprises three components: the direction of contact, the radial contact distance, and the extent of contact. When laser cut springs suspend a compliant whisker, contact forces cause both rotation and translation at the whisker's base. By tracking 9 points on the suspension system, we can determine the rotation and z-translation of the whisker base. B) Pure z-translation proportionally changes the position of the tracked points in the camera image relative to the image center. C) Pure rotation creates opposite motions of the tracked points in the camera image relative to their position to the whisker's center of rotation. The arrows represent 10x the motion of the point in pixels.

the array shape, and a segmentation algorithm determines the new shape computationally (Fig 1C). Once the array shape is determined, the magnets' rotation and elastomer's motion are tracked from below using trackers from python's open cv package. This methodology gives the magnitude of rotation of a whisker accurate to $0.5°$ and the direction of rotation accurate to $6.5°$ (Fig 1B). Finally, the whiskers' response to contact is distinct from its response to airflow or inertial stimuli, allowing signals from contact and noncontact stimuli to be differentiated. Unsurprisingly, when sensors can localize the contact point along the whiskers' length, the efficiency of 3-d spacial mappings increases [2]. Most methods of radial contact determination rely on knowing the extent of contact (Fig 2A) to reliably determining the radial contact height within 10 % of the whisker's total length [2, 5, 8, 9]. These methods require semi-rigid surfaces as the extent of contact can not be measured on objects which deform while the whisker deforms. One method suggests that by measuring the downward force on a tapered compliant whisker, one can solve for the radial contact distance without knowing the extent of contact [3]. Switching the elastomer suspension of the WhiskSight sensor for a spring suspension with a signal maximizing design, we gain the ability to detect downward deflections caused by axial forces in the tapered whisker (Fig 2B,C). The downward force during the compliant whisker bending is dependent on the radial contact height (Fig 2A). When sensed downward deflection and the rotation signals are used as inputs, an algorithm can quantify the likelihood that contact is occurring on a rigid surface. This metric allows a future robotic implementation to sense quickly in predictable environments while slowing down when the sensed signals are less clear.

The two sensors represent progress engineered whiskers that can overcome some of the challenges from uncertain environments: robustness, opportunities for error, and information density. With continued improvements in engineered whisker sensors, the robots that employ these sensors can make informed decisions about their interactions with their environment.

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