ARTIFICIAL ACTIVE WHISKERS FOR GUIDING UNDERWATER AUTONOMOUS WALKING ROBOTS

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A low-cost, biologically inspired underwater walking robot (see Fig. 1) has been designed and built to covertly explore the seabed and to determine properties of submerged objects in obscure and inaccessible underwater locations. This paper focuses on a preliminary evaluation of an artificial active whisker to instrument this platform. Results demonstrate that both range and bearing to objects contacted by the whisker can be determined using simple data driven heuristics.

Keywords: Biomimetic; whisker; underwater robots; legged locomotion

1. Introduction

Adopting legged locomotion for traversing the seabed has a number of operational advantages; firstly, the platform can maintain its position without expending energy[1] ; secondly, the typically unstructured terrain of the sea bed can be scaled efficiently; and thirdly, movement generates a low acoustic signature which, for applications such as mine clearance or littoral warfare, would be beneficial. One of the problems to overcome using legged marine locomotion is how to sense the environment around the platform. The proximity to the sea bed inhibits the effectiveness of acoustic (sonar) based sensing[2] whilst the motion of the legs will disturb the sediment thus impairing the performance of any machine vision based solution.

Taking inspiration from nature we find that many marine mammals use facial whiskers to explore the seabed and catch prey using their sense of touch.[3] Similarly, many other marine animals, such as lobsters and shrimps, also employ touch to explore their environment using active (moving) antennae. One of the principal differences between mammalian whiskers and the antennae of invertebrates is that the sensory afferents, or mechanore-

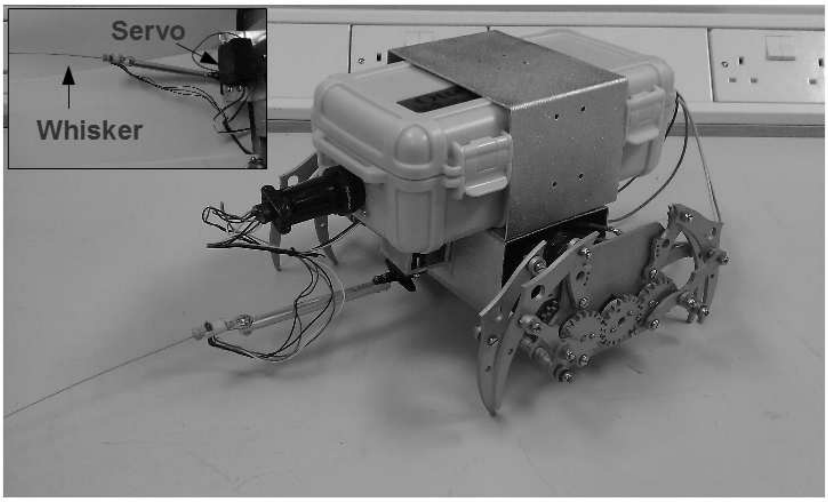

Fig. 1. photo of machalobster showing detail of whisker attachment

ceptors, of the invertebrate antennae are distribution along the length of the appendage. In mammalian facial whiskers the mechanoreceptors are all located at the base with the whisker shaft itself composed of, effectively, dead hair cells.[4] From an engineering perspective developing a touch sensor based on the facial whiskers of marine mammals would, therefore, be a less expensive and potentially more robust solution than a fully instrumented active antennae.[5] However, the derived sensory information will be less rich and may require more processing to determine the location and other properties (such as surface form or texture) of any contacted objects.

Here we report on the preliminary evaluation of a bio-inspired active whisker based sensor for determining the bearing and range to objects encountered by a legged underwater robot. The design of the robotic platform, hereafter referred to as MechaLobster (shown in Fig. 1), is described in the methods section along with the whisker sensor and the experimental setup used to evaluate its performance in both air and water. The results focus on investigating data driven approaches for determining heuristics for bearing and range estimation following whisker contacts when operating in both media.

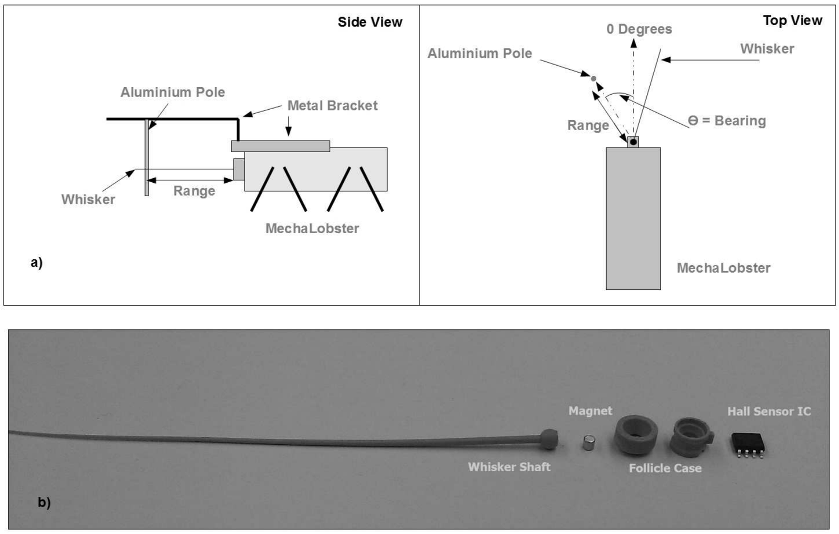

Fig. 2. **a)**schematic of experimental setup and **b)** exploded view of whisker sensor

2. Method

Mechalobster measures 170x550x260mm and is composed of; a watertight, negatively buoyant controller and battery housing (OtterBox); two modified MFA drill motors (1:148 gearbox) driving the Klann linkage[6] inspired leg mechanism; and a waterproof Traxxas 2065 servo to actuate a flexible, 150mm long whisker instrumented with a Hall effect based sensor. The whisker is sensitive to deflections of the shaft in 2 axes; however, here we constrain our evaluation to deflections measured only around the dorsal-ventral axis of the robot, i.e., in the same plane as the actuated degree of whisker motion. The deflections of the shaft are converted into a proportional voltage by the Hall Sensor at the base and are sampled at 250Hz using the 10-bit ADC module of a dsPIC30F4011 micro-controller located in the watertight controller housing. This sensory information, along with the current angle of the whisker drive servo, is packaged and transmitted via an ER400TRS radio module and logged using a remote PC. This 433Mhz radio signal can reasonably penetrate up to half a metre of water, which allows real-time sensory monitoring when the robot is located at the bottom of a laboratory based testing tank.

The experimental setup for generating the preliminary data set was as follows: (Shown in Fig.2a) A 400mm long metal bracket that can be rotated around the dorsal-ventral axis of the robot was attached to the top of MechaLobster directly above the centre of rotation of the whisker drive servo. An aluminium pole was then clamped to this bracket at various points along its length such that the whisker will make contact with the pole at specific distances along its own length and at a particular bearing with respect to the centre of servo rotation. Sinusoidal drive patterns of various frequencies and magnitudes (referred to as whisking) were then applied to the whisker servo such that the whisker would contact and deflect against the aluminium pole which, in turn, was set at various ranges and bearings. The first data set was gathered with the platform out of the water before being repeated with the platform immersed in water.

3. Results

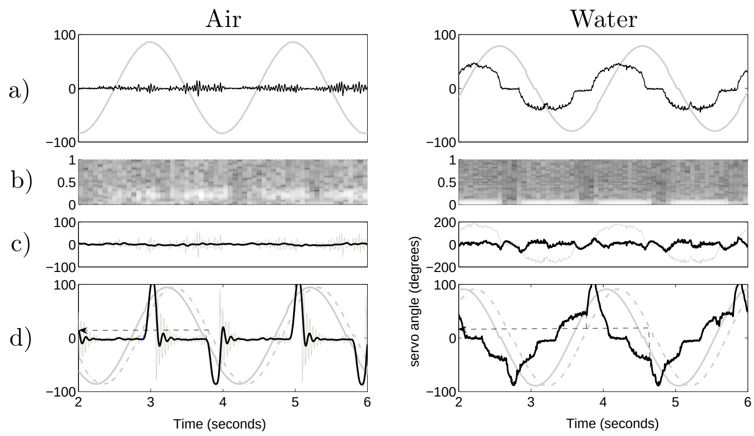

Fig. 3. Determining bearing to contact from active whisker data collected in air and water, **a)** Time series of 'free-whisking'; Grey traces are the demanded servo drive signals and black are the scaled and overlaid whisker deflection signals. **b)** Spectrogram of free-whisking data; Frequency range normalised to half sample rate (i.e., 125Hz). **c)** Black traces are low-pass (air) and high-pass (water) filtered versions of the original grey data. **(d)** Contacting a pole located at 15 degrees bearing; dashed grey traces are lag compensated whisker angles, dashed arrows indicate inferred bearing to contact.

The self-motion induced whisker signals in air were dominated by the resonant frequency of the whisker (25Hz, see Fig.3b). In water, the dominant time series feature is the derivative of the driven whisker motion, i.e., 0.5 Hz. Whisking in air can be adequately cleaned using a simple low-pass filter (8th order Butterworth, see Fig. 3c), however, an equally simple high-pass filter applied to water based whisking was found to be inappropriate (see Fig. 3c). In previous works[7] a bio-inspired de-correlation adaptive filter model of the cerebellum was used to compensate for similar 're-afferent' noise and would be a good candidate for this application. For subsequent work reported here, the air whisking data was low-pass filtered and the water based signals remained unfiltered. A visual inspection of the data set whilst whisking into a pole aligned 15 degrees from the centre line of the robot was made to determine the phase lag introduced by the filter and the response of the servo drive (see Fig. 3d). In air, this was found to be 36 degrees whilst in water a 60 degree lead was found to be appropriate for reliably determining bearing to contact (as indicated by the blue arrows). In future work the actual whisker angle will be measured using a shaft encoder to derive more accurate bearing estimates. To determine range to

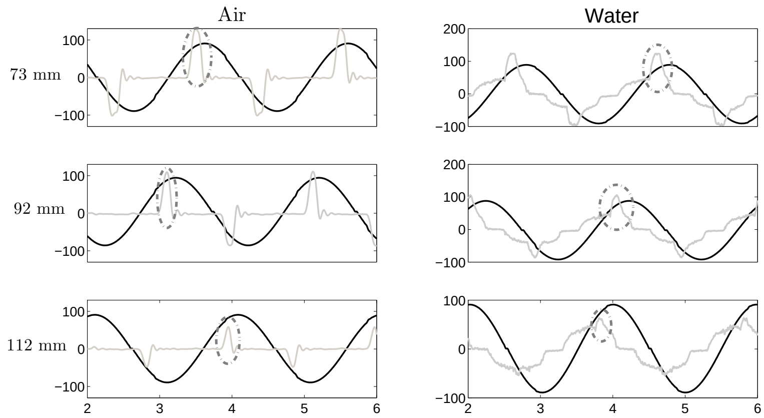

Fig. 4. Determining range to contact from active whisker data collected in air and water into a pole set at 3 different radial distances from the base of the whisker. Axes same as figure 3, dashed ellipses indicate contact incidences

contact, a data set was gathered whisking in air and water at 0.5Hz into a vertical pole, set at a fixed bearing, at three different radial distances from the base of the whisker (73mm, 92mm and 112mm, see Fig. 4). A simple feature that can be used to determine range to contact has been shown as the peak magnitude of the whisker deflection during the whisk.[8] This heuristic is born out in both air and water whisking by a visual inspection of the data set in Fig. 4.

4. Discussion and future work

These encouraging results support further investigation of active whiskers for underwater sensing. It is now known that information for contact localisation is contained in the data but that more experiments are needed. The next phase of work will be to gather a larger control set with which to train a feature based template classifier (based on this preliminary set) to autonomously extract both range and bearing information. This will then be used to orient and direct the movement of the legged robot as it explores to build a tactile map of the seabed. The control of the whisker motion is also an area of particular interest as the classification of more detailed surface features, such as texture[9] or orientation, will require fine motor control to constrain the sensory range.[10]

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