“Seashell Effect” Pretouch for Robot Grasping

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I. INTRODUCTION

A. *Robotic Pretouch Sensing*

The term “Pretouch” refers to sensing modalities that are shorter range than vision but longer range than tactile sensing. The hypothesis that pretouch sensing can be useful for manipulation is being explored actively [1][2][3][4][5]. It is viewed as potentially beneficial for manipulation because it provides reliable geometric information in the last centimeter before contact. The disadvantage of using tactile sensing for collecting local geometric information is that contacting the object may displace it— an outcome that is particularly likely when the object’s geometry is initially uncertain. An advantage of pretouch over vision is that pretouch is not subject to the problem of the hand occluding the camera, because the sensor is integrated into the hand; another is that there are no camera-to-hand registration errors since the sensor is in the coordinate frame of the hand.

This paper introduces a new form of pretouch that works with a wider variety of materials than our earlier electric-field based pretouch [1][2][3]. The paper illustrates the advantages of pretouch over contact sensing by demonstrating that pretouch can detect objects that are too compliant for the PR2’s tactile sensors to detect.

B. *Seashell Effect*

There is a well-known folk myth that if one holds a seashell to the ear, one can hear the sound of the ocean. The rushing sound that one hears is in fact the noise of the surrounding environment, resonating within the cavity of the shell. The same effect can be produced with any resonant cavity, such as an empty cup or even by simply cupping one’s hand over one’s ear. The resonator is simply amplifying the ambient noise in the environment, including air flowing within the resonator, corresponding to the resonant mode of the specific cavity [6]. It is easily verified that the perceived sound depends on the position of the seashell with respect to the head. Inspired by this seashell effect, we propose the use of a microphone cartridge in an acoustic cavity to measure the distance to the object surface by sensing changes in the measured noise spectrum.

C. *Acoustic Theory*

The radiation impedance of an open-ended tube has a small but finite value. Its imaginary part acts as an end correction to the geometrical tube length from which the resonance frequency of the tube is calculated. Dalmont [7] found an empircal formula for the end correction in this kind of pipe-surface configuration by fitting a function to values produced by a finite element model.

The end correction δ_{obj} caused by the approaching object is given by:

$$\delta_{obj} = \frac{a}{3.5(h/a)^{0.8}(h/a+3w/a)^{-0.4}+30(h/d)^{2.6}}$$

where a, w are the radius and wall thickness of the pipe; h is the distance between the object and pipe opening, and d is the radius of the object. The formula shows the approaching object will increase the end correction, and thus decrease the resonance frequency in the pipe. The resonance frequencies with different parameters computed based on this formula are compared with our experimental data and shown in Figure 1 (L is the length of the pipe).

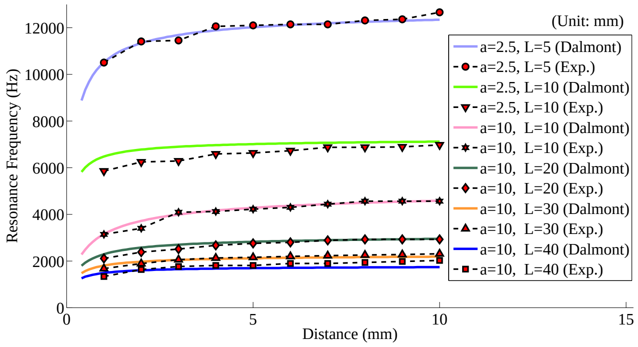

Fig. 1. Comparison of theoretical and experimental resonance frequencies

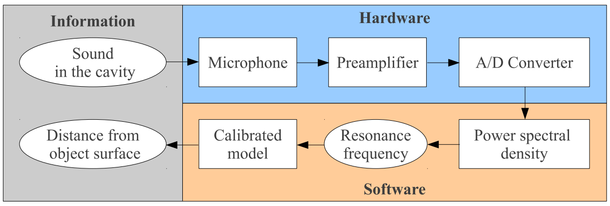

Fig. 2. System architecture

II. SYSTEM DESIGN

The system is comprised of hardware and software components. Figure 2 shows the schematic of the system.

The sound in the cavity is collected by a electret condenser microphone catridge (WM-61A, Panasonic) with sampling rate of 44,100 Hz. The signal is amplified and converted to digital by an audio interface. The cavity used in our

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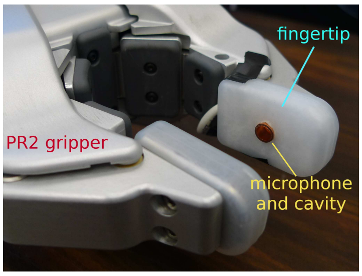

Fig. 3. The seashell effect pretouch sensing fingertip on PR2 gripper

prototype is a 2.5 mm radius / 5 mm length cylindrical pipe. A completed fingertip prototype installed on the PR2 gripper is shown in Figure 3.

The power spectrum of the signal is estimated every 0.05 second (N = 2205) using Welch spectrum estimation (Ns = 1024; overlap ratio = 70%; Hanning data taper). The distance measurement is then carried out by finding the fundamental resonance frequency in the spectrum and mapping it to the pre-calibrated frequency-distance function. The software is implemented in Python as a ROS node, which continuously publishes the resonance frequency, total signal energy, and distance as ROS messages at the rate of 20 Hz.

III. EXPERIMENT

A pre-grasping experiment was performed, in which the pressure sensor built in to the PR2's gripper was compared to our seashell effect pretouch sensor. The two sensors were applied in a pre-grasp task to four different objects with different compliance. The objects used were a cookie box, a disposable cup, a folded paper box, and a folded aluminum foil box.

In the force sensing trial, the PR2's pressure sensor fingertips are installed on both right and left fingers on the PR2 right gripper. The standard PR2 gripper sensor controller is used to detect contact with objects. The default pressure threshold is used such that false positive detection is avoided.

In the pretouch trial, the seashell effect pretouch sensor is installed on one of the fingers on the PR2 right gripper. The gripper is commanded to close until the fingertip is sufficiently close to the object according to the seashell sensor.

A trial is defined as successful if the gripper stops before sqeezing so much that it breaks the object. The pressure sensor is able to detect the contact for cookie box and disposable cup, but it is not able to sense the contact with the extremely compliant folded paper and aluminum foil boxes, thus breaks them. On the other hand, the seashell effect pretouch sensor is able to sense all the four objects and stop the gripper at an approppriate distance from the object, which shapes the pre-grasp pose. (Table I).

An interative mode which the gripper dynamically adjusts its opening based on the seashell effect pretouch sensor is also demontrated.

TABLE I
RESULTS OF EXPERIMENTS

Objects	Pressure	Seasehll pretouch
cookie box	∨	∨
disposable cup	∨	∨
folded paper box	×	∨
folded aluminum foil box	×	∨

IV. CONCLUSIONS AND FUTURE WORK

A. Conclusions

This paper demonstrates a novel acoustic pretouch modality for robotic grasping inspired by the well-known seashell effect. As far as we know, this effect has not previously been used to build proximity sensors. A fingertip prototype based on this priciple was built and installed on PR2 gripper. We demonstrate that this technique is useful for sensing extremely compliant and moving objects, which can not be detected by the standard pressure sensors on the PR2 fingertip.

B. Future Work

The integration of the seashell effect pretouch fingertip to the exsisting SPI interface on the PR2 gripper is in progress. The next generation of the system will have seashell effect sensors on both fingertips without external wires. (In our initial implementation, an external cable to the sensor is used.) We plan to make pretouch sensors available to other PR2 users.

We plan to apply seashell effect pretouch to grasping extremely compliant objects (taking the next step beyond the pre-shaping demonstrated here). We will also explore the use of pretouch sensing in conjunction with the PR2's existing depth sensors, to provide data on portions of the object where information is missing, either because of occlusion, or depth sensor failure. Given a partial pointcloud collected by a depth sensor, our pretouch sensor (combined with robot kinematic data) will be used to add additional points to the cloud, prior to grasp planning.

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