Reactive control of a robot hand equipped with visual-haptic sensor for pre-grasp shaping and gentle touch

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***Abstract*— In this work, we make use of the proximity measurements from a visual-haptic sensor (PCF sensor) to develop a reflex-like behavior for a five-fingered robot hand to dynamically adapt to object shape and also gently touch them without moving or damaging them. We empirically validate our method using a motion capture system to track the position of the object before and after a grasp.**

I. INTRODUCTION

The natural approach to grasp can be broadly divided into three phases; i) object selection, ii) hand transport and pre-grasp shaping phase and finally, iii) grip phase. After the object of interest is chosen the hand approaches the object while simultaneously also pre-shaping according to the objects properties and anticipated use based on a priori knowledge [1], [2]. Finally the grip phase involves final movement of the fingers touching the object for gentle pick up and manipulation thereafter.

Visual feedback provides great deal of information about the environment and objects necessary for object selection, grasp planning and manipulation purpose. Tactile feedback on the other hand helps interpret the physical interactions of the object with the hand. Visual data however inherently suffers in low lightning conditions and occlusion form the hand itself. Hence, it is not suitable to accurately track the shape and position of the object during pre-grasp and grasp phase. Moreover, controlling a robot hand with high degree of freedom (DOF) is challenging given such inaccurate information from a vision sensor.

Pre-grasp shaping of the robot hand using proximity sensors on the fingertips reduces the complexity of controlling the hand to adapt to objects of varying sizes and shapes. Moreover, measuring the magnitude and location of contact eliminates the possibility of moving or damaging the object with imperfect contact forces. In this work we particularly focus on creating a reflex like behaviour for pre-grasp and grasp phases using the upgraded design of the PCF sensor [3] and a five-fingered robot hand. To the best of our knowledge this is the first attempt to use proximity signals for pre-grasp shaping and gently touching objects of unknown shapes with a five fingered robot hand.

II. RELATED WORK

Using simple infrared distance sensors to reactively control a robot hand has been proposed as early as 1985 [4]. Since then there have been several attempts to install proximity sensors on robot finger tips for a variety of applications. [5] developed a net-structure of proximity sensors to measure proximity, contact and slip. Along similar direction [6] installed proximity sensors on finger tips of robot TUM-Rosie to reconstruct 3D geometry of objects, classify material properties and measure slip. [7] used proximity sensing to achieve robustness in a sequential manipulation of solving a rubix cube by aligning one dimensional pre-touch scan to a pre-existing reference point cloud. Use of 6-axis force/torque sensors to determine contact and its locations has been previously studied by [8], [9]. However, the form factor, power and wiring requirements of such sensors restricts their usage to only certain kind of robot hands and in certain controlled conditions.

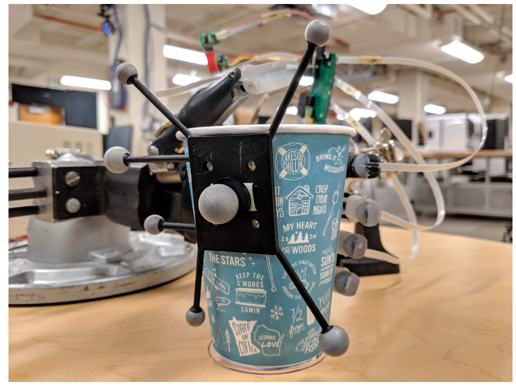

Fig. 1: Bebionic hand equipped with PCF sensors on the fingertips. Markers are attached to the cup to track its position using a motion capture system

Closest to our approach for pre-grasp shaping using proximity sensing and utility of contact detection is work previously presented by [10] and [11]. The authors in [10] utilize sensors similar to one developed by [5] to orient fingers of a three-fingered robot hand around object of four basic shapes. [11] showed the utility of contact detection for faster completion of manipulation tasks in upper limb prosthesis devices. None of the sensors used in the work mentioned above provide proximity, contact, magnitude and location of force measurements in one single package. This does not allow them to easily transition from the pre-grasp phase to the grasp phase like us.

III. METHOD

A. Experimental setup

The experimental setup consists of a five fingered Bebionic V2 prosthetic hand (RSL Steeper Inc.) equipped with the upgraded PCF sensors [3] as shown in Figure 1. The upgraded PCF sensor consists of a MEMS–based barometric pressure sensor (MS5637-02BA03), in addition to the infrared proximity sensor (VCNL4040) [12]. Both are embedded inside an elastomer (rubber) layer. The resulting visual-haptic sensor can measure proximity, contact and force and also has the ability localize contact at eight discrete locations.

The robot hand has six DOFs. One DOF for each finger to open and close and one additional DOF in the thumb joint for abduction. We replaced the original electronics of the hand with custom built motor controller boards from Sigenics Inc. The motor controller boards have an in-built PID position controller. The motors can also be driven by pulse width modulated (PWM) signal.

We also make use a motion camera system to track the 6D pose of the object to provide an absolute change in its position before and after a grasp. For this we attach 7 markers on a cup as shown in Figure 1. We place the markers such that their 6D position is tracked by four cameras.

B. Approach

For pre-grasp shaping we chose to use a simple Proportional Derivative and Integral (PID) controller to control the position of the fingers based on the proximity signals. Input to the controller were normalized proximity values from PCF sensor and output of the controller was the PWM control signal for the finger motors. We tuned the PID gains for each of the fingers individually such that all fingers maintain a constant distance from an object.

In the contact detection phase the fingers are moved slowly moved towards the object with a constant PWM signal such that once contact is detected the finger motors are stopped. We measure contact by averaging (or smoothing) the raw proximity signal with an exponential averaging filter and subtract the original signal from this smoothed signal. Both the controllers are written in C programming language to avoid delays associated with transferring data over USB serial bus to the host computer. With this we obtain a decent response at around 100 Hz.

We start the experiment by placing a cup at a fixed location within the aperture of the hand. The performance of the both controllers is tested against the case where no controller is used. A 10g dead weight is placed in cup initially to balance the torque created by the markers. Weights are then incrementally added in the cup. Each trial consists of the hand initially fully open. An input from the experimenter sets the hand in the pre-grasp shaping mode. In this mode the fingers dynamically maintain a constant distant from the objects. Once all the fingers stop moving another input from the experimenter sets the hand in the grasp mode where the fingers gently move until contact is detected. Next trial starts by replacing the weight in the cup with next higher weight. The robot hand is fully opened and the cup is placed in the fixed location. Same steps are repeated for the case where no controller is used. In this case the robot fingers are position controlled to move to a set location where the cup is positioned.

IV. RESULT

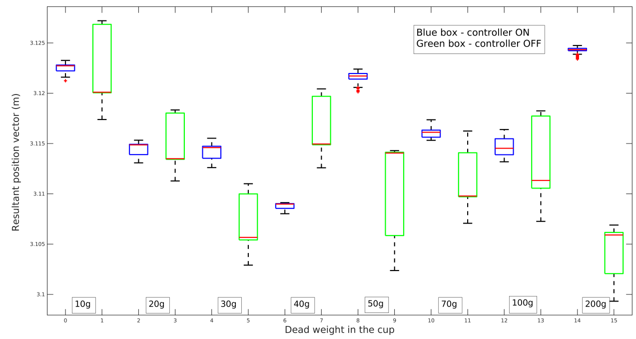

Fig. 2: Change in the position of a cup when different dead weights are placed in it and for cases with and without a controller for pre-grasp shaping and contact detection

The change in the resultant translational position of the cup before and after a grasp for a total of 16 trials is shown the form of a box plot in Figure 2. The top and bottom line in each box roughly represents change in initial and final position of the cup. Blue boxes are results when the controller is on and green boxes are the ones when the controller is off. It is clearly visible from the plot that in case when the controller is on the change in position of cup is significantly less than when the controller is off (example see box positioned at zero and one). Again, as the dead weight in the cup is increased there is notable decrease in the movement of the cup when the controller is on. This change is not so remarkable in case when the controller is off. There are few outliers for example box positioned at 9, 11 and 12. These are attributed to the poor repeatability of the movements of the robot fingers.

V. CONCLUSIONS AND FUTURE WORK

In conclusion we have presented a simple technique to pre-shape a five fingered robot hand and gently touch objects based on the proximity signals from a visual-haptic sensor. In future work we plan to come up with a model or an on-the-fly calibration routine that would encode color dependence of the infrared proximity sensor. This would allow to extend our approach to objects with any surface reflectively. We also plan to add a grip force control strategy into our current approach to pick up object with optimal force without damaging them. The motor friction of the robot fingers is not consistent across the entire range of the finger from fully open to fully close. Therefore, a single set of PID gains or PWM value for each finger does not allow the intended function of the finger. Sometimes it results in excessive motion while sometimes no motion at all. We also plan to address this issue by either using different set of gains for different functional regions of the finger or by using some form of model predictive approach. We believe that development of such a reflex like control of a multi-fingered robot hand will dramatically improve grasp success and also help in effortless control of a upper limb prosthesis devices.

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