Object Feature Reconstruction via Robotic In-Hand-Manipulation and Haptic Proprioception

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Abstract. In this extended abstract we demonstrate that within-grasp object localisation and size estimation can be achieved without tactile sensors, using only a simple 3DOF robotic manipulator and proprioceptive sensing from inexpensive actuators. A geometry-based algorithm is used, based on 4-bar linkage kinematics, modified to match the structure of our gripper when holding a convex object, such as a cube.

1 INTRODUCTION

In robotics, the ability to determine object and grasp properties by touch has been investigated for many years. More recently, it has been demonstrated that in-hand-manipulation (IHM) can be used to enhance tactile data collection, by exposing more of an object's surface to tactile sensor surfaces [2, 5]. The potential for tactile object identification without tactile sensors was explored in [4], where time series actuator position and current was reduced to several key points and fed to a classification algorithm. In this work we go beyond object classification and aim to estimate physical parameters of an object's size and pose within the gripper. Our method estimates object location and size based on a kinematic representation of the hand-object model as a four-bar linkage whose parameters can be estimated using the Freudenstein equation [1].

2 IMPLEMENTATION

2.1 Gripper

To focus on the algorithmic challenges of the in-hand proprioception problem, we focus our efforts on planar manipulation. We make use of a new gripper in this work, called the MinE-TRoll, which is a miniature and simplified version of the open-source E-TRoll (Extended-Tactile Rolling) gripper of [5].

The gripper consists of two rigid fingers with a single revolute joint at the base of each. The two revolute joints are mounted on a prismatic dual-rack-and-pinion joint, which enables their linear separation to be adjusted.

Two types of manipulation are used to gather proprioceptive data about the held object. These are a fixed-base rolling manipulation (previously used in [4, 2, 3]) and a new manipulation strategy which we call 'palm-pivot'. These manipulations are executed by the gripper sequentially, following an initial grasp (Fig 1).

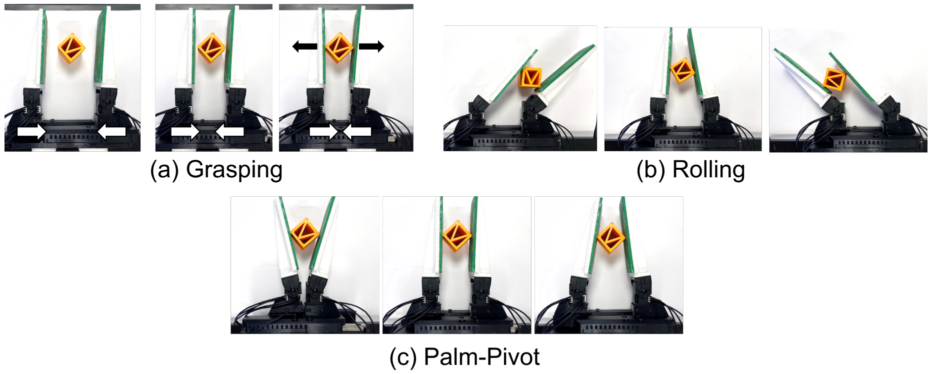

Fig. 1. The 3 in-hand-manipulations undertaken by the MinE-Troll gripper.

2.2 Kinematic Model and Parameter Solver

The relationship between the *MinE-TRoll* fingers and an object can be kinematically modelled as a four-bar linkage mechanical system with parameters as shown in Fig 2. The palm width aperture is represented by a, and c is the estimated object size. Angles ψ and ϕ represent the angles, and b and d the distances, from the centre of the finger joints to the object contact points. The relationship 1 between the parameters is derived from Freudenstein's Equations [1].

$$R_1 \cos(\phi) - R_2 \cos(\psi) + R_3 - \cos(\phi - \psi) = 0 \tag{1}$$

where,

$$A = (1+R_1)\cos(\phi)+R_2+R_3, B = -2\sin(\phi), C = (R_1-1)\cos(\phi)-R_2+R_3 \tag{2}$$

$$R_1 = \frac{a}{d}, R_2 = \frac{a}{b}, R_3 = \frac{a^2+b^2-c^2+d^2}{2bd} \tag{3}$$

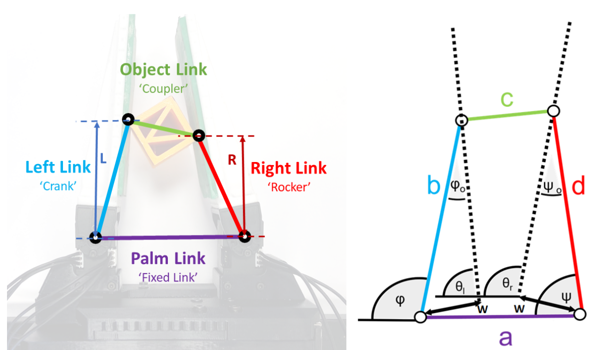

Fig. 2. The relationship between the fingers and object may be represented by a four-bar mechanism, assuming point contacts.

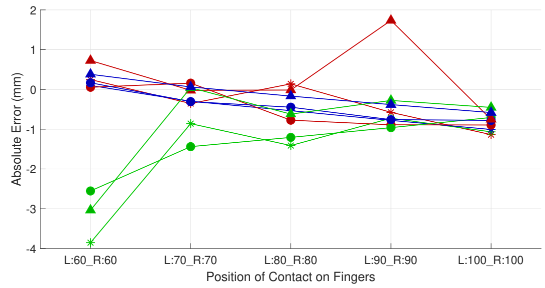

Fig. 3. Object size estimation error for different manipulations and object sizes with symmetrical initial contact points. Note that a legend would not fit on this plot but is the same as in Fig 4.

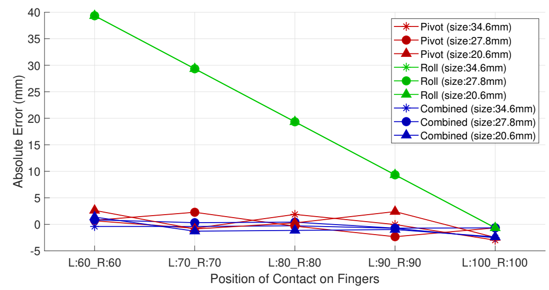

Fig. 4. Left finger contact point estimation error with symmetrical initial contact points.

Due to the offset w caused by the width of the finger, there is no direct measurement of angles ϕ and ψ. The measured joint angles θ_l and θ_r are related to ϕ and ψ by equation 4.

$$\phi = \theta_l + \arcsin(w/b) \quad \psi = \theta_r - \arcsin(w/d) \tag{4}$$

Observations of a, θ_l and θ_r (from the actuator encoders) during IHM are substituted into the above equations to form a vector of nonlinear functions with each component in the form $f_i(a_i, \theta_{l_i}, \theta_{r_i}, b, c, d) = 0$. MATLABs nonlinear least squares solver was used to find a set of parameters b,c,d which minimise the sum of squares of the component residuals. These parameters are optimal estimations of the contact point locations and proximity.

3 RESULTS

The manipulation test procedure involved two sequential phases of motion, a $\pm 15mm$ palm-pivot manipulation followed by a $\pm 10°$ rolling manipulation. Parameter estimation was performed using data from each phase of the manipulation separately and combined.

Figure 3 shows the absolute error for object size estimation for different (symmetrical) initial contact positions on the fingers and object sizes. Figure 4 shows the absolute error for contact points estimation on the left finger (the plot for the right finger is not shown but is very similar). The results shown also consider the different manipulation strategy used to generate the data, red colors represent palm-pivot actions, green series represent rolling actions, and blue colors represent the combined estimation considering both actions. Better size estimation is achieved for the combined pivoting and rolling data rather than either individually. Size estimation error with combined data is less than $\pm 1mm$. Position estimation is unacceptable with rolling data alone, with combined data giving marginal improvements over pivoting alone. Position estimation error with the combined data is approximately $\pm 5mm$.

4 CONCLUSION AND FUTURE WORK

This work has introduced a kinematic model based parameter estimation algorithm that uses only actuator encoder data to reconstruct the physical properties of an object being manipulated. We demonstrate the approach on practical data collected from the MinE-TRoll, a custom-built and inexpensive 3DOF robotic gripper. The 3D-printed nature of the gripper, inexpensive actuators (Dynamixel XC330-T288-T) and slipping of objects against the fingers introduces various forms of noise and positioning error. Despite this our algorithm performs well, giving object size estimation error within 5% of an object's size.

Key to exploiting the algorithm is the use of multiple In-Hand-Manipulation actions during data collections. It was demonstrated that combining typical rolling manipulation with a new palm-pivot action greatly reduces size and position prediction error. This pivoting action is made possible by the variable width palm of the MinE-TRoll robotic gripper. In future work we will investigate the effect of varying palm width also for rolling motions, to keep the fingers parallel during this action, as in [5]. We also plan to expand the objects under examination to include those with curved and irregular cross-sections. Finally, the relationship between object starting position and overall accuracy may also be further studied, as this parameter is bound to vary in practical applications.

References

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