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A MOTION PLANNING SCHEME FOR ROBOTIC IN-HAND OBJECT MANIPULATION

Hyunhwan Jeong[1], Joono Cheong[2] and Wheekuk Kim[3]

Dep. of Control & Instrumentation Engineering in Korea University , 2511, Sejong-ro, Jochiwon-eup, 339-700, Sejong, Korea
[1]hyunhwanjeong@korea.ac.kr [2]jncheong@korea.ac.kr, [3]wheekuk@korea.ac.kr

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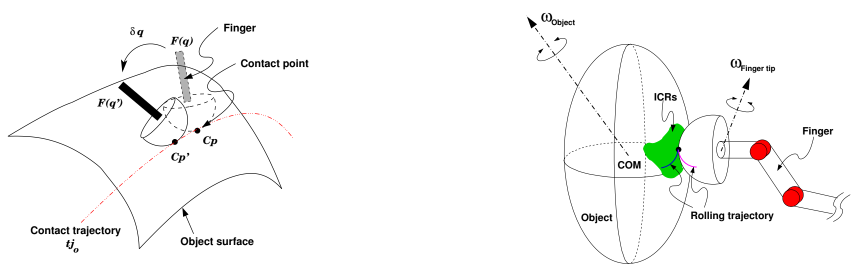
This paper propose a new novel in-hand manipulation planning scheme to smoothly move a grasped object with rolling. While most previous methods had to calculate complicated contact equations between contact fingers and object surface[1], the proposed method does not use this equations and thus the generation of such in-hand motion becomes relatively easy. We use 3D surface data of the object (which includes the object points and normal vectors to local surfaces), and our computer algorithm can autonomously generate the desired motion of an object. This method guarantees a stable grasp during the object manipulation, which is a key result different from previous works. In order to manipulate the grasped object to produce a desired motion, we calculate the rolling contact trajectory of the contact finger on the object surface. Fig.1(a) shows a schematic of the rolling contact. The contact point has to change from C_p to C'_p on the trajectory Tj_o for making the object undergo translation δT_o and rotation $\delta(\theta)\times R_o$ with respect to object coordinate frame. Then, the total displacement of the object becomes $tj_o(C_p) - tj_o(C'_p)$. By the relation between the finger-tip displacement and object displacement, it is written that

$$tj_o(Cp) - tj_o(Cp') = \delta e_q = \delta T_o + \delta\theta \times R_o, \qquad (1)$$

where δe_q is the variance of finger-tip point due to the rolling. In this rolling process, we



(a) Schematic of rolling contact (b) Rolling manipulation

Figure 1: Rolling contact model

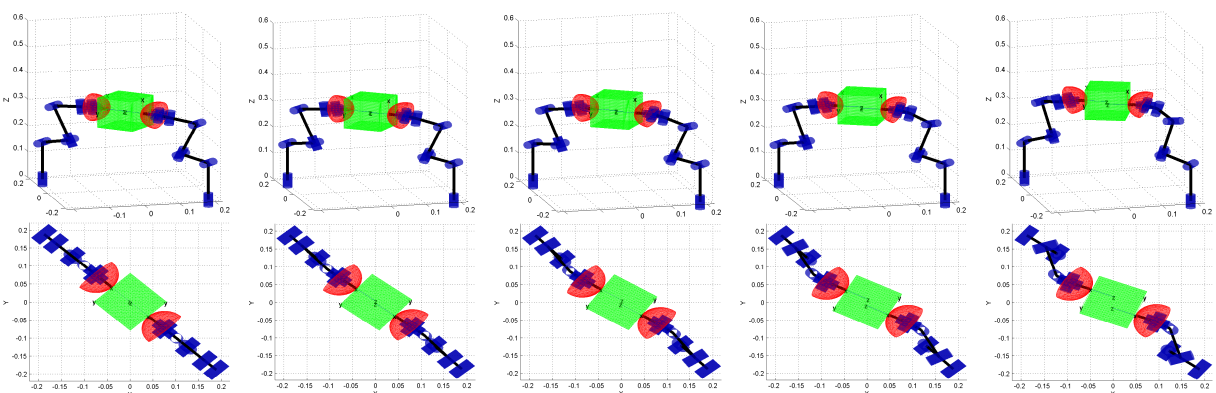
used the concept of independent contact regions (ICRs) as shown in Fig.1 (b). If contact trajectories are generated on ICRs, the grasp is alway stable during the rolling motion [2]. Let object moves by screw motion which consists of wrench w and translation constant d. From the desired screw motion, we can find desired contract trajectory in the half space of ICRs as follows.

$$tj_{ICRs} \subset (HP^{+}_{Pn_{w_{obj}}} \cap HP^{+}_{Pt_{C_p}}), \tag{2}$$

where Pt_{C_p} is a tangential plane of current contact on the ICRs and $Pn_{w_{obj}}$ is a plane which has wrench vector of object screw motion as normal vector to the plane. Letting any finger tip shapes as a half sphere, the finger tip motion that tracks the trajectory is generated by the following equation.

$$\delta\theta_{F_{tip}} = Dist_{Tj_{C_{ICRs}}}/r_{Ftip}, \quad W_{Ftip} = V_{C_p - P_c} \times Vt_{tj_{C_{ICRs}}} \tag{3}$$

where, r_{Ftip} is radius of finger tip, $V_{C_p-P_c}$ is a vector from center of finger tip to current contact point of the finger. To show the validity of our study, we conducted some simulation on in-hand manipulation using the proposed method. Fig.2 shows the simulation results. As shown, the proposed algorithm autonomously produced a motion to achieve the desired in-hand manipulation task. [1]



(a) $t = 0s$ (b) $t = 0.5s$ (c) $t = 1.0s$ (d) $t = 1.5s$ (e) $t = 2s$

Figure 2: Simulation Result

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