Finger Surface Following Control through Intrinsic Contact Sensing

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Abstract—A surface following finger is an indispensable mechanism to enable a dexterous robotic hand to recognize and study the surface properties of an object, namely, texture, material type and contours [1][2]. To follow an arbitrary surface geometry, a vision and proximity sensing based approach have been investigated in [3] and [4]. Force/tactile based methods are reported in [5] and [6]. However, to effectively follow a complex shape with rapidly changing surface contours is still a challenging problem. In this paper, we take advantage of instantaneous identification of normal and tangential force vectors provided by the force/torque based intrinsic contact sensing methods [7][8] and develop surface following control methods which allow a finger to follow a surface with rapidly changing geometry without prior knowledge of the surface shape. In this paper, two methods, velocity ratio control and position/impedance control, are introduced.

I. SURFACE FOLLOWING USING VELOCITY CONTROL METHOD

A case study was carried out using a two-joint finger. The direction of the fingertip’s motion can be decided by the velocity ratio between the two motors at the respective joints. Therefore, surface following can be achieved by controlling the velocity ratios. Further detail is available in [9]. A force control scheme for generating fingertip motion depending on the desired force vectors is shown in figure 1.

Given the position in the next time step, the desired joint angles (θ₁, ..., θₙ) are determined through inverse kinematics. The fingertip motion is controlled by calculated velocity ratios to allow for smooth motion, an efficient execution time and to be adaptive to a wide range of normal forces. Further details of the velocity ratio control are available in [9].

The f denotes either the normal force fₙ or tangential force fₜ depending on the condition as shown in figure 2. k is a constant coefficient.

\[ p_{t+1} = p_t + k \left( \frac{f}{\|f\|} \right) \]  

The trajectory result of surface following using velocity control is shown in figure 4.

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Figure 1 Force control diagram with 2DOF finger

Figure 3 Normal force control result of velocity control (Blue : 0.2N to 0.4N, Black : 0.6N to 0.8N, and Red: 0.8N to 1N )

Figure 4 The trajectory results of surface following using velocity control
The calculated velocity ratios are applied using a PID velocity controller. To evaluate the velocity control method, three different desired normal force ranges were tested and the results show that the normal force is maintained within the desired range while following the surfaces, Fig. 3. As shown in Fig 4, the surface following provides enough accuracy to recognize the object’s surface geometry. Also, following the surface using velocity control smoothes the fingertip trajectory.

II. SURFACE FOLLOWING USING POSITION CONTROL METHOD

In this section, surface following using position control was tested. The virtual shadow hand was simulated in ROS with the Gazebo simulator.

Due to the natural compliance of the cable driven system of the shadow hand, the desired position of the fingertip should virtually indent into the surface to create an impedance force. Thus, an impedance control function \( k(f_n) \) is implemented instead of Eq. 1 to control the normal force \( f_n \), and hence \( p_{t+1} \) is adjusted depending on the desired normal force.

\[
p_{t+1} = p_t + k(f_n) \frac{f_n}{||f_n||} \tag{2}
\]

When the normal force is within the desired range, Eq.1 is implemented to move the fingertip so that it follows the direction of the tangential force. The joint rotation is determined using inverse kinematics, and controlled by each joint’s PID position controller instead of PID velocity controller. When the current normal force is out of the desired normal force range, the PID position controller is switched to the impedance control, Eq.2. In this case, the impedance control function \( k(f_n) \) in Eq. 2 is required to adjust the coefficient \( k \) according to the desired normal force. Simulation results indicate that the position controller is able to achieve the desired normal force as shown in figure 6.

III. REFERENCES