# 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.

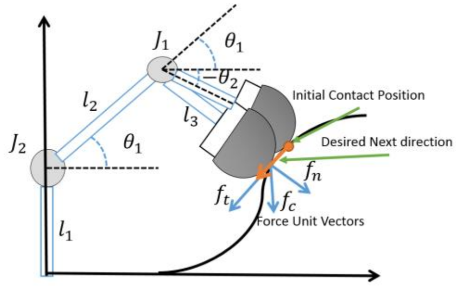


Figure 1 Force control diagram with 2DOF finger

In these control experiments, the fingertip follows the direction of the tangential and normal forces. These forces are generated by the velocity and position of the fingertip, so that the next position of the fingertip is dictated by the direction of a selected force.

The current finger position in Cartesian space is denoted as $\boldsymbol{p}$ and the position at next time step as $\boldsymbol{p}_{t+1}$. The next position of the fingertip is calculated using:

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$$\boldsymbol{p}_{t+1} = \boldsymbol{p}_t + k\left(\frac{\boldsymbol{f}}{\|\boldsymbol{f}\|}\right) \tag{1}$$

The $\boldsymbol{f}$ denotes either the normal force $\boldsymbol{f_n}$ or tangential force $\boldsymbol{f_t}$ depending on the condition as shown in figure 2. $k$ is a constant coefficient.

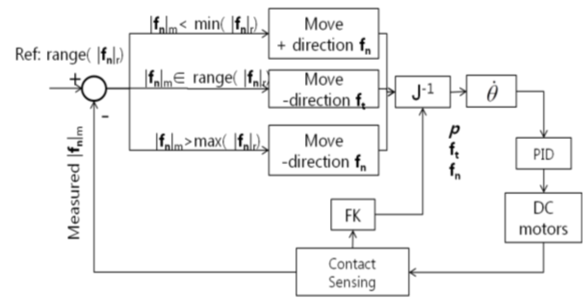


Figure 2 surface following control system with velocity control

Given the position in the next time step, the desired joint angles $(\theta_1, .., \theta_n)$ 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].

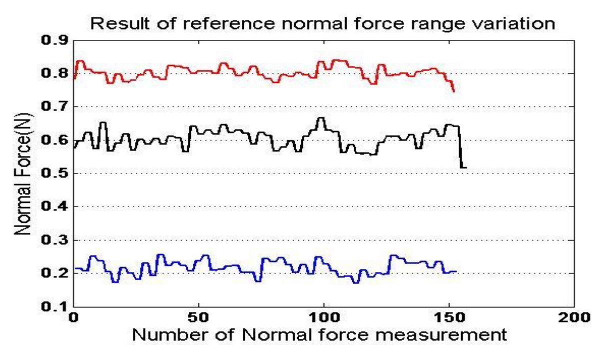


Figure 3 Normal force control result of velocity control
(Blue : 0.2N to 0.4N, Black : 0.6N to 0.8N, and Red: 0.8N to 1N )

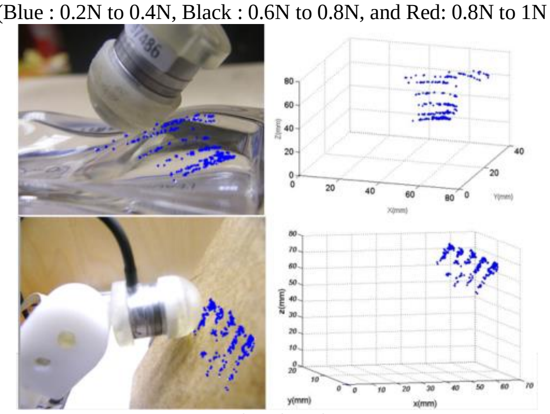

Figure 4 The trajectory results of surface following using velocity control

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 smoothens 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.

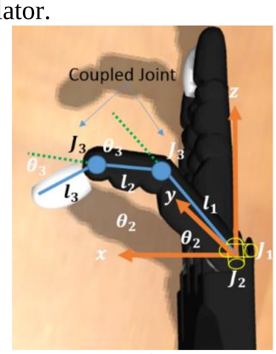


Figure 5 Shadow hand finger(3DOF) diagram

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 $k(\boldsymbol{f}_n)$ is implemented instead of Eq. 1 to control the normal force $\boldsymbol{f}_n$, and hence $\boldsymbol{p}_{t+1}$ is adjusted depending on the desired normal force.

$$\boldsymbol{p}_{t+1} = \boldsymbol{p}_t + k(\boldsymbol{f}_n)\left(\frac{\boldsymbol{f}}{\|\boldsymbol{f}\|}\right) \qquad (2)$$

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.

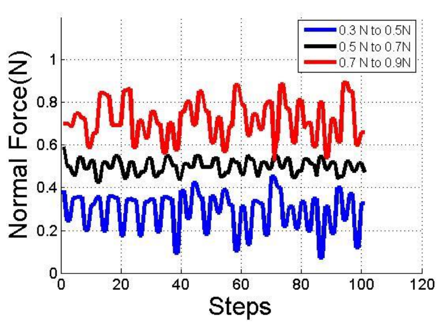


Figure 6 Normal force control results using position control

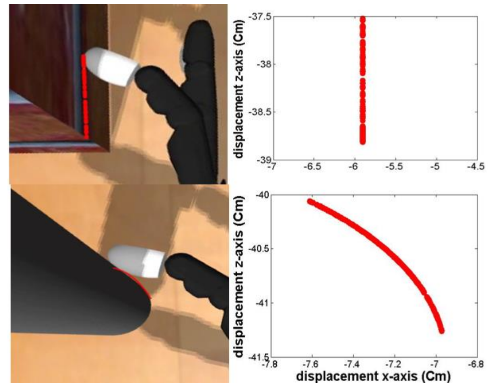


Figure 7 The trajectory result of surface following with position control

As shown in figure 7, the controller performs well when following the straight and the curved geometries.

Exploiting this capability of instantaneous normal/tangential force vector identification is enabled by the intrinsic sensing method of an embedded 6-axis force/torque sensor. We introduce two simple control methods for surface following. Overall, the velocity ratio control performs better than the position/impedance control in terms of trajectory smoothness, accuracy and reactiveness. However, the position control method has the advantage of being ready for implementation in existing cable driven dexterous robotic hands.

## III. References


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