Fingertip force control for grasping and in-hand manipulation

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1. Motivation

Grasping and in-hand manipulation is acting on an object via hard/soft contacts of the palm and fingers. Dexterous manipulation mainly uses, however, only fingertip contacts (which is different from power grasping). The forces generated by these contacts should neither too strong (that break the object) nor too weak (unable to lift the object). They should be moreover properly coordinated in order to give the object the desired motion. Fingertip force control plays hence a very important role in grasping and dexterous manipulation.

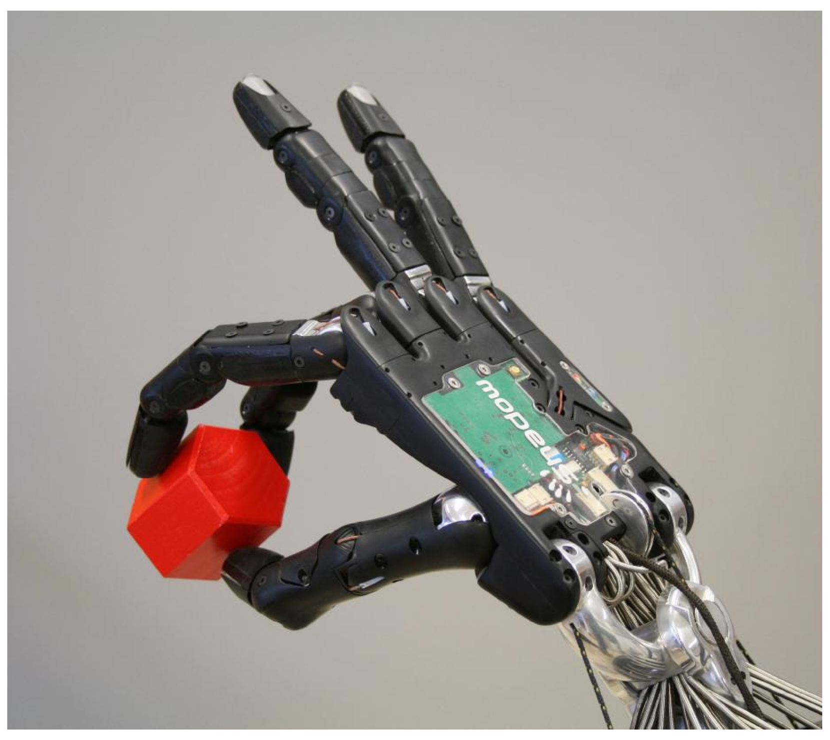


Figure 1: *Shadow hand grasping an object*

There are two main types of fingertip force control used in the planning algorithms of grasping and in-hand manipulation:

- **Direct force control**: hybrid position/force control
- **Indirect force control**: compliance, stiffness or impedance control

Most of the current planning algorithms for grasping and dexterous manipulation using direct force control [3] but indirect force control appears to be also quite efficient for these tasks.
We concentrate our efforts firstly on the algorithms of direct force control (hybrid position/force control in particular). The indirect force control is our objective in the next steps.

2. Theory

Hybrid position/force control

The main control algorithm which is used here is hybrid external control [4]. This control scheme is characterized by the hierachical juxtaposition of the force-control loop over the position-control loop. It has numerous advantages over other algorithms (such as parallel scheme of Craig and Raibert [5]):

- simple calculation, does not need selection matrix and other geometric transformation
- can deal with imperfect modelling of environment surface
- easy used for multi-robot (finger) cooperation

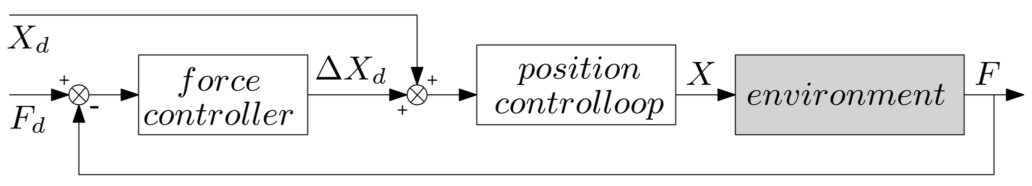


Figure 2: *Hybrid external control*

Impedance control

Impedance control appears to be particularly useful for certain grasp planners thanks for its unique form of set-point [2].

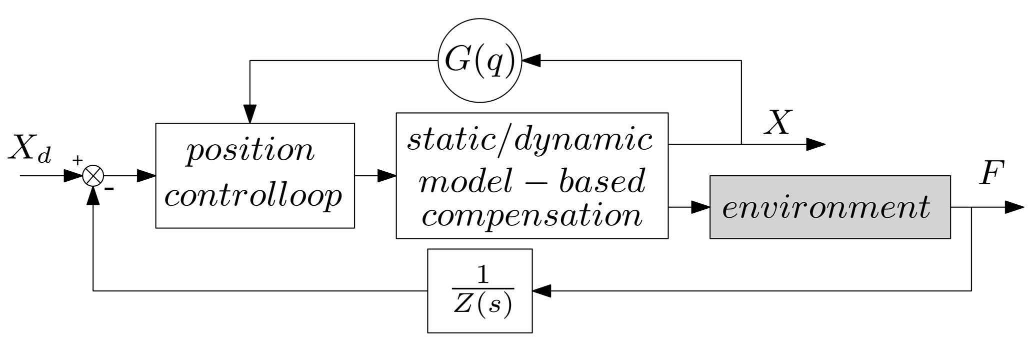


Figure 3: *Impedance control with inner motion control loop*

The impedance function Z is typically of the "stiffness-damping-inertia" form: $Z(s) = M\ddot{x} + K_D\dot{x} + K_P(x - x_0)$ where M, K_D and K_P are control gains.

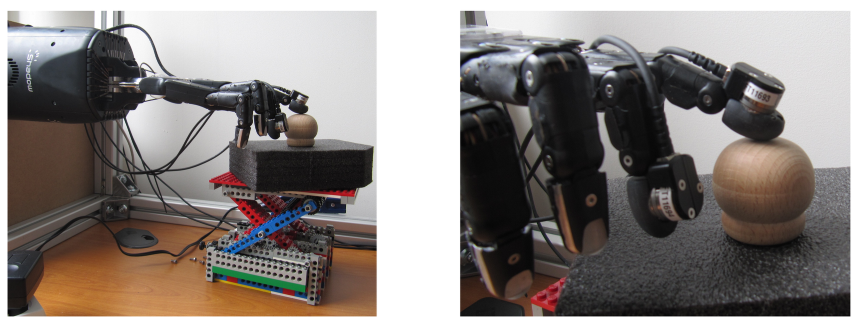
3. Experiments

Experiment apparatus

The apparatus used in these experiments contains:

- Motor version of the Shadow hand C6M2 [6]
- KCL tactile sensor [1]

All the equipments mentioned above are connected to ROS environment.



(a) (b)

Figure 4: *Force control using Shadow hand*

Implemented control scheme

For this part of the works, we implemented the hybrid external position-force control scheme (figure 2 for the first finger and middle finger of the Shadow hand. The joint position controller used in this scheme is the "mixed position velocity" given by Shadow company.
The control parameters for the force control loop is $k_i = 0.09$ and the other parameters for the joint position controllers are given in the table 1.

Joint name	$k_{p(pos)}$	$k_{i(pos)}$	$k_{d(pos)}$	$k_{p(velo)}$	$k_{i(velo)}$	$k_{d(velo)}$
FFJ0	-4.0	0.0	-3.5	-250.0	0.0	-810.0
FFJ3	-4.0	0.0	-3.5	210.0	0.0	710.0
FFJ4	-4.0	0.0	-3.5	-210.0	0.0	-710.0
MFJ0	-4.0	0.0	-3.5	-250.0	0.0	-810.0
MFJ3	-4.0	0.0	-3.5	210.0	0.0	710.0
MFJ4	-2.0	0.0	-2.5	-110.0	0.0	-170.0

Table 1: *Joint control parameters*

Results

For middle finger with desired force $F_d = 1N$, the static error is small ($\sim 0N$) but the response time is slow ($\sim 5s$) (figure 5).

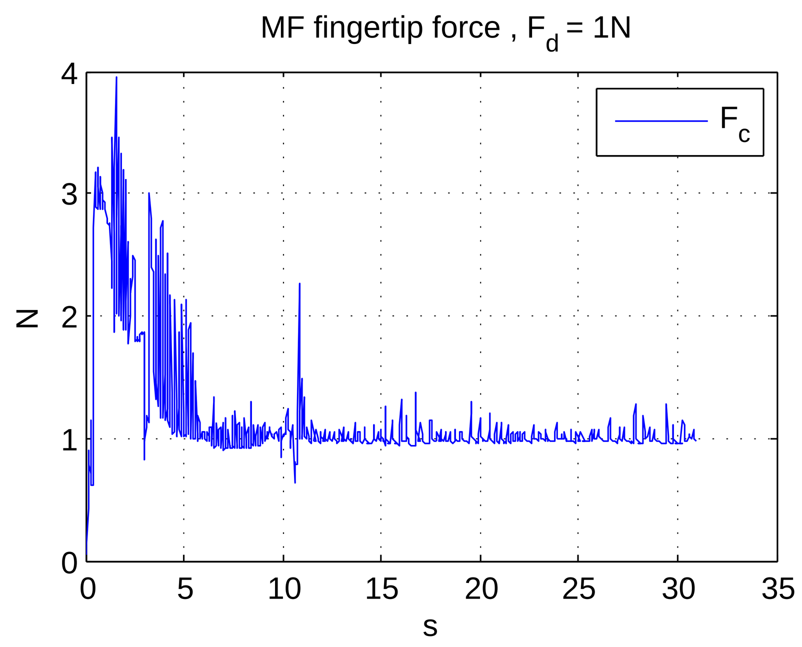


Figure 5: *Middle finger: $F_d = 1N$*

The control loop is not very repeatable: sometimes, it gives a strange response (figure 6).

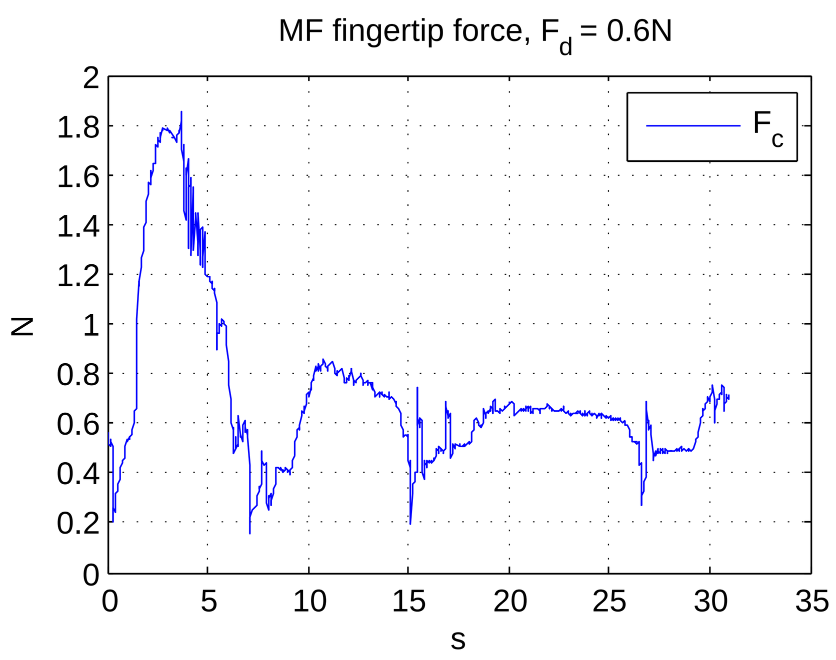


Figure 6: *Irregular response for middle finger*

This is partially due to the joint position controller mentioned above. An experiment having the FFJ3 moving from $0°$ to $10°$ and then back to $0°$ shows the this controller is

- slow with number of delays in free space movement(figure 7)
- not repeatable (figure 8)

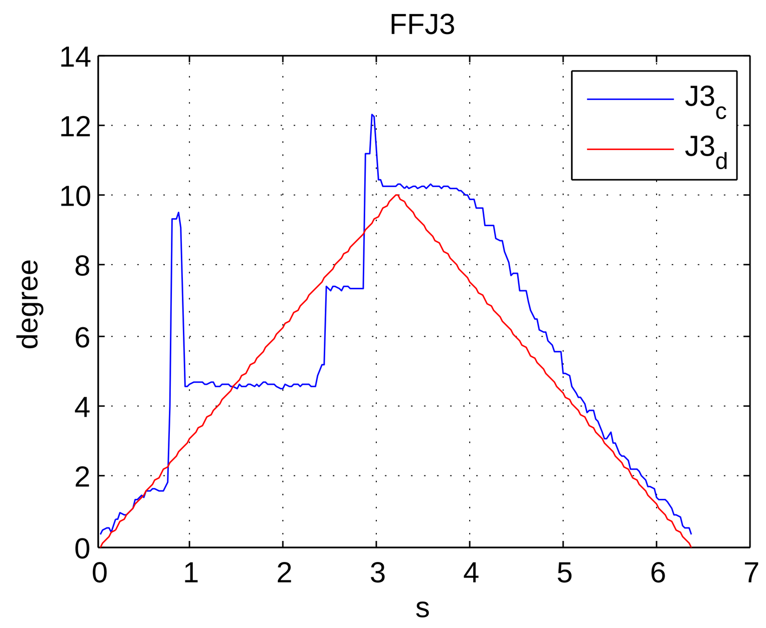


Figure 7: *FFJ3 response*

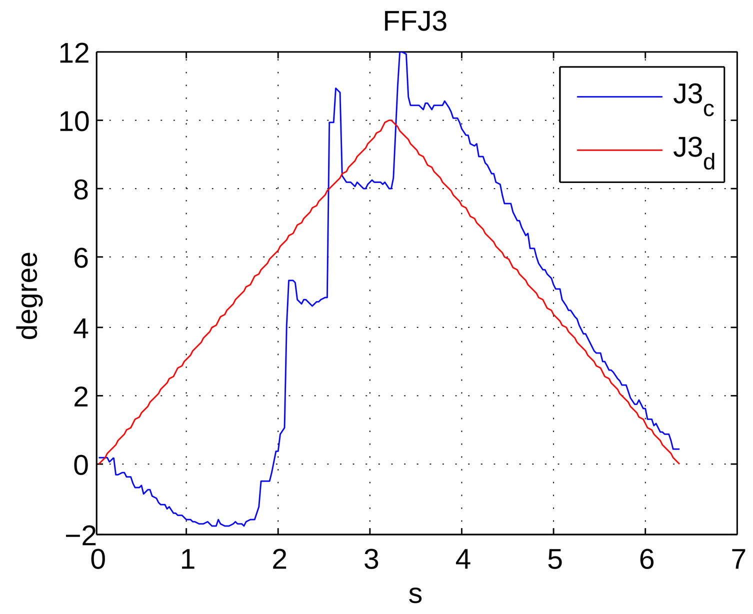


Figure 8: *FFJ3 irregular response*

This clearly shows the need of improving the joint position controller at the lower level.

4. Conclusion and Future Work

Our approach and first implementation of the hybrid external force control give positive results. However, there are numerous limits (slow and unrepeatable responses) which are particularly due to the limits of the joint position controllers at the lower level.
Our objectives for the next steps are then:

- improve the joint position controllers
- improve the hybrid position-force control
- implement the impedance control loop for the fingers

References

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[6] Shadow robot company. www.shadowrobot.com.

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