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Strategy of Internal Force Design without Object CoM Information

Joonhee Jo[1,2], Sung-Kyun Kim[1], Yonghwan Oh[1] and Sang-Rok Oh[1]

[1]Interaction & Robotics Research Center, KIST, Seoul, 136-791, Korea,
[2]Department of HCI & Robotics, UST, Daejeon, 305-350, Korea
(Tel : +82-2-958-5758; E-mail: jhjo, kimsk, oyh, sroh@kist.re.kr)

Abstract - There are a variety of methods to grasp an object. An internal force control is used to grasp an object and be compliant when an external disturbance is applied. simultaneously. An internal force control for a ball type object is not proper for a box type object grasping due to the error between an origin of the object reference frame and information about the center of mass (CoM) of the object. This paper considers dynamic situation during internal force control and suggests a proper control strategy for box type objects compared to the ball type object. To validate the proposed algorithm, internal force control using Allegro hand is conducted and showed competent results.

Keywords - Internal force control, robotic hand, stable grasping, and grasping strategy.

1. Introduction

From the advent of robotics research, development of a human-like robotic hand has been a hot issue. Those researches are not for the industry robot but for service robots. Industrial robots have to work fast and precisely. No disturbances are allowed during work. However, in the case of service robots, they have to be robust against external disturbances and compliant since they work with unexpected disturbances.

Some research such as Robonaut is focused on an under-actuated hand using passive joints, and some other research is focused on a fully-actuated hand with active joints. In the case of an under-actuated system, the robot grasps an object based on a passivity control with compliant motion. On the other hand, a fully-actuated system with active joints requires more exclusive controller for grasping and manipulation of an object.

Grasping without any external disturbances without information about the center of mass (CoM) of the object has been accomplished through a joint position control, end-effector position control, and so on [1]. Basically, those control methods does not allow manipulating an object with external disturbances with compliant motion. Hence, a sensory feedback from a force/torque sensor is used to interact with disturbances during grasping [2]. In the case without sensory feedback, torque based control using current control can be an option. Current control has great advantage in the point that it shows compliant motion without sensory feedback.

However, considering the robot-object system dynamics, grasping through torque based control is still difficult because it requires much information such as object weight and CoM. Khatib et. al. [3] used virtual linkage, Arimoto et. al. used finger-thumb opposition [4], Bonitz et. al. used force decomposition [5]. If finger forces applied to an object are decomposed into motion-inducing force and internal force, manipulation of an object is getting simpler.

Among the decomposed forces, internal force contributes to stable grasping of the object. However, general internal force control could not be formulated for all kinds of grasping since it is dependent on the shapes of objects and selection of an object reference frame.

In addition, interaction force control usually uses the centroid which is the center of fingers when no information of object weight and CoM is given. However, this can make the robot unstable during manipulation, and to draft while it grasps a box type object.

In this paper, a strategy of internal force control for a box type object grasping without information about the CoM of the object is considered. Internal force control in dynamic situation for manipulation is discussed in section 2, and a grasping strategy and control law design for a box type object are proposed in section 3. In addition, to validate the algorithm, an experiment is performed and the results are shown in section 4. At the end, section 5 concludes the paper.

2. Internal Force Control without Information about Center of Mass

Consider a robotic hand and object system described in Figure 1. The hand grasps an object with frictional point contact. Each finger cannot apply moments but

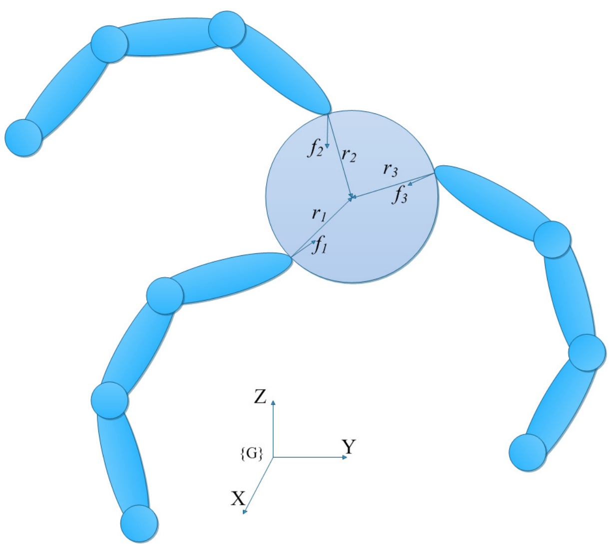


Fig. 1 Internal force control scheme using a centroid.

pushing forces only. Definition of the terms in Figure 1 is:

$\boldsymbol{\mu}_{obj}$: Applied force about an origin of the object frame.
$\boldsymbol{\sigma}_{obj}$: Applied moment about an origin of the object frame with respect to the global frame.
$\boldsymbol{f}_i$: End-effecor force of i-th finger.
$\boldsymbol{r}_i$: Position vector from end-effector to $\boldsymbol{O}_{obj}$.
$\boldsymbol{O}_{obj}$: Origin of the object frame.
$\boldsymbol{p}_i$: End-effector position of fingers.
$\boldsymbol{J}_o$: Object Jacobian mapping between object net force and end-effector of fingers.

Applied net forces to the object, $\boldsymbol{f}_{obj}$, can be expressed using end-effector forces as

$$\boldsymbol{f}_{obj} = \boldsymbol{J}_o^T \boldsymbol{f}, \tag{1}$$

where $\boldsymbol{f}_{obj} = \begin{bmatrix}\boldsymbol{\mu}_{obj} & \boldsymbol{\sigma}_{obj}\end{bmatrix}^T$, $\boldsymbol{f} = [\boldsymbol{f}_1 \quad \boldsymbol{f}_2 \quad \boldsymbol{f}_3]^T$. $\boldsymbol{J}_o^T$ is defined as

$$\boldsymbol{J}_o^T = \begin{bmatrix} \boldsymbol{E}_3 & \boldsymbol{E}_3 & \boldsymbol{E}_3 \\ -(\boldsymbol{r}_1) & -(\boldsymbol{r}_2) & -(\boldsymbol{r}_3) \end{bmatrix}$$
$$\text{where}(\boldsymbol{r}_i) = \begin{bmatrix} 0 & -r_{i,z} & r_{i,y} \\ r_{i,z} & 0 & -r_{i,x} \\ -r_{i,y} & r_{i,x} & 0 \end{bmatrix} (i = 1, 2, 3), \tag{2}$$

where $\boldsymbol{r}_i = \boldsymbol{O}_{obj} - \boldsymbol{p}_i$, and $\boldsymbol{E}_3$ is the identity matrix in three dimensional space. $(\boldsymbol{r}_i)$ is a skew-symmetric matrix.

To decide $\boldsymbol{O}_{obj}$ is important in grasping an object. If $\boldsymbol{O}_{obj}$ is chosen as CoM, the control will be succeed properly because the physical phenomenon of the object occurs about CoM. However, if the CoM information is not given, $\boldsymbol{O}_{obj}$ should be chosen in an artificial rule. That makes an error between $\boldsymbol{O}_{obj}$ and CoM, and an unexpected moment may occur due to the error. The moment error changes according to the decision rule of $\boldsymbol{O}_{obj}$ and configuration of the fingers. Time-varying position of $\boldsymbol{O}_{obj}$ with respect to the object can make the robot-object system unstable. Hence, it is necessary to decide a fixed $\boldsymbol{O}_{obj}$ to reduce the moment error effect and make the system more stable.

Let one finger at least is below the object and the finger is in contact during grasping. If a lower finger is not contacted with an object, the object will be dropped and grasping will be failed. Then, the distance between positions of the end-effector and CoM is constant during the whole process. The distance between two points is an error and the error makes moment error. If the moment error doesnt change, the error can be compensated by control appropriately. Hence, more stable robot-object system can be achieved. In addition, f can be decomposed into

$$\begin{aligned} \boldsymbol{f} &= \boldsymbol{f}_M + \boldsymbol{f}_I & (3) \\ &= \boldsymbol{P}_M \boldsymbol{f} + \boldsymbol{P}_I \boldsymbol{f}^* & (4) \end{aligned}$$

where $\boldsymbol{f}_M$ and $\boldsymbol{f}_I$are the motion inducing force and the internal force w.r.t. the global frame respectively, and $\boldsymbol{P}_M$ and $\boldsymbol{P}_I$ are the projection matrices to a motion inducing force space and an internal force space respectively. $\boldsymbol{f}^*$ is in the null space of the motion inducing force. In this paper, the internal force control is mainly focused.

3. Grasping Strategy with Different Object Type

Basically, the objects for grasping have different shapes and sizes. A proper grasping can be achieved when the fingers apply force in a friction cone. If tangential force to the object surface is large compared to the normal force, the applied force may be outside the friction cone, which can cause finger slipping. Therefore, the grasping strategy should be different according to the object type, and it can be accomplished by choosing proper $\boldsymbol{f}^*$ and its initial position.

3.1 Ball Type Object

When the robot grasps a ball type object, applying force close to perpendicular direction to the object surface makes the finger force in a friction cone. In addition, because the ball type object has round shape on the surface, a centroid which is the center of contact points can be used.

$$\boldsymbol{f}^* = c(\frac{1}{n}\sum_k^n \boldsymbol{p}_k - \boldsymbol{p}_i) = c(\boldsymbol{p}_c - \boldsymbol{p}_i) \tag{5}$$

where c is a constant which represents a force scale, and $\boldsymbol{p}_c$ is the centroid which is the center of fingers. Each finger applies a force toward centroid and the force can be in friction cone without slippage.

As shown in Figure 1, ball type object can be grasped appropriately because the direction of a grasping force is in the friction cone on the surface of the object, and it does not make fingers slipping on the surface.

3.2 Box Type Object

In the case of box type object, as shown in Figure 2, if centroid is used, a tangential force would be so large that

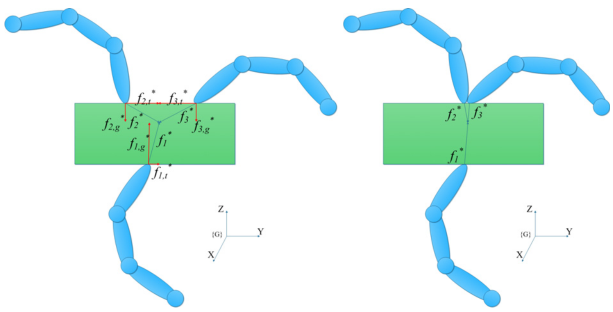


Fig. 2 Internal force control using a centroid in determining $\boldsymbol{f}_i^*$ with box type object. Fingers gather closer to centroid in tangent direction of the object surface due to tangential force.

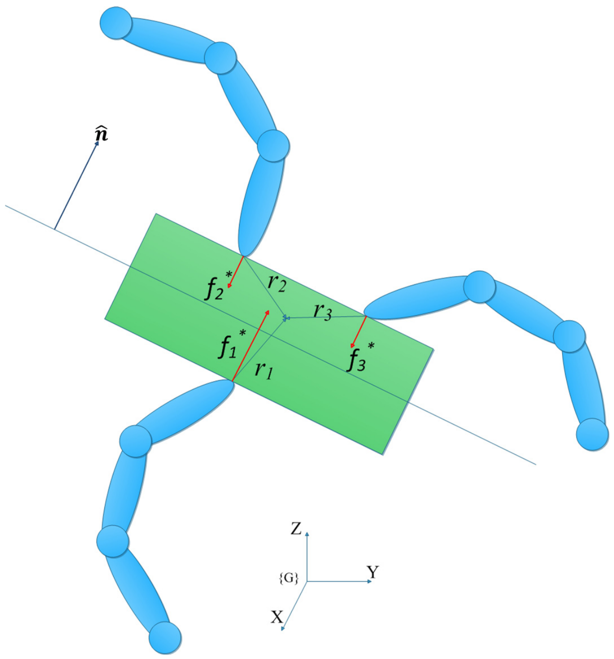


Fig. 3 Internal force control with proper initial contact and applying force normal to the object surface.

the force makes finger slipping. In that case, the slipping fingers gather together along the object surface, and the object can be easily swung. It makes the object more unstable with small disturbance. Hence, as shown in Figure 3, the internal force should be changed as follows:

$$\boldsymbol{f}_i^* = \begin{cases} c\hat{\boldsymbol{n}} & (\boldsymbol{p}_c - \boldsymbol{p}_i) > 0 \\ -c\hat{\boldsymbol{n}} & (\boldsymbol{p}_c - \boldsymbol{p}_i) < 0 \end{cases} \tag{6}$$

where $\hat{n}$ is the box object surface normal vector, and c is the constant value which represents a force scale. $\hat{\boldsymbol{e}}_z$ is the unit vector which has anti-gravitational direction.

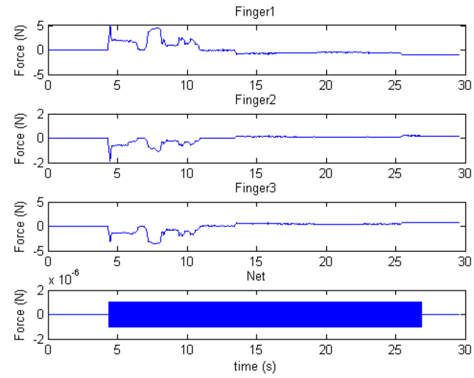
4. Experiment

4.1 Hardware Specs

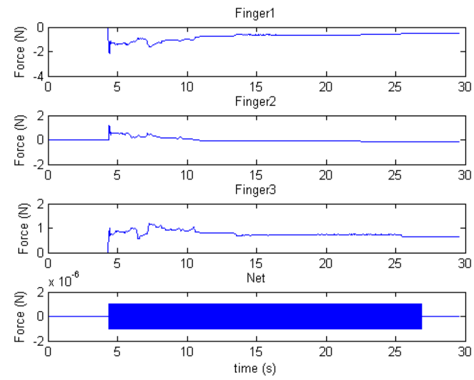
Fig. 4 Allegro hand.

To validate the algorithms, experiments are conducted using Allegro hand which has 16 degrees of freedom (DOF) and 1.08 Kg of its weight. Allegro hand which is from SimLab Co. in Figure 4 is actuated by DC motors and controlled using current control running by 1 KHz of control period. Joint angle value is measured by potentiometer and obtained through ADC board. The robotic hand and PC is communicated by EtherCAT and real-Time Extension (RTX) is used for real time control in windows.

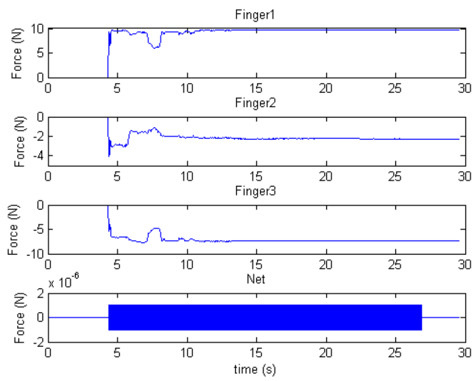
4.2 Internal Force Control Experiment



(a) X-axis internal force



(b) y-axis internal force



(c) z-axis internal force

Fig. 5 Experiment result of internal force control using suggested algorithm for box type object.

The experiment is conducted using an algorithm for box type object to show the proper box grasping. To validate the internal force control working appropriately, internal force values are measured. While the hand grasps the object, disturbances are applied on the object to check whether the hand grasps an object properly or not. Graphs show the result of internal force control during box type object grasping. In the Figure 5, Finger 1 represents the thumb of Allegro hand, Finger 2 is the index, and Finger 3 is the third. Sums of each axis of finger forces are zero in the object frame, and it shows proper internal force control is conducted. If the control fails, the sums of each axis internal forces are not zero.

5. Conclusion

The internal force control for box type object using Allegro hand is conducted in this paper. The difference between internal force control using centroid and fixed point which is proposed in this paper is discussed. In addition, grasping an object with one controller is difficult because of a different shape of objects. Firstly, internal force control for a ball type object is introduced. In addition, the strategy to grasp a box type object is discussed compared to the method for ball type object. The paper describes a reason why a ball type object control is not appropriate for a box type object control.

Validating an algorithm is conducted using Allegro hand and showed competent results. The controller works with box type object properly.

Next considerations are on a motion force control with an internal force control, a sensory feedback force control, and an indirect contact force control with external disturbances on an object.

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