Efficient Grasp Synthesis and Control Strategy for Robot Hand-Arm System

Ming-Bao Huang, Han-Pang Huang, *Member, IEEE,* Chih-Chun Cheng, and Ching-An Cheng
Mechanical Engineering Department, National Taiwan University, Taipei, Taiwan, 10617, R.O.C.
phone: +886-2-3366-2700; fax: +886-2-2363-3875; e-mail: hanpang@ntu.edu.tw

Emerging Technologies on Industrial Robotics and Manufacturing Automation

---

***Keywords*— Robot hand, Hand-Arm system, Grasping, Impedance control**

EXTENDED ABSTRACT

This research is aimed to improve the efficiency of grasping with hand-arm system. It is divided into two parts: The first part proposes a simplified grasping condition for grasp planning and uses the tactile sensors at fingertip to control the interaction impedance for a robot hand to handle uncertainties in real-world applications. The second part extends the previous techniques from the robot hand to a full robot hand-arm system, and a four-stage planning is designed to generate an ideal grasp trajectory. We demonstrate the whole system by illustrating how our humanoid robot—NINO—with NTU-Hand V would open a door. By adopting this research in arm-hand coordination, mobile robots or humanoid robots can perform grasping and manipulating tasks to improve our daily lives.

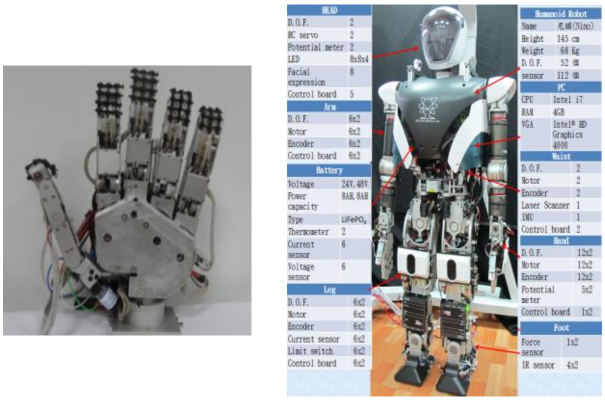
A. Methods

This research presents a simplified grasp synthesis and control approach for practical applications [1]. We consider a system with single-point tactile sensors at the robot hand's fingertips. The main idea is to simplify the grasping condition and uses two levels controls, impedance control at the fingertips and position at the end-effector, to achieve compliant behavior in grasping, so the hand-arm system can use frictional forces to efficiently grasp an object with uncertainties without breaking it.

To simplify the grasping condition, we restrict that the contacts lie on a same plane and assume that the contact model is point contact with friction. Under this assumption, when the sum of forces and moments balance, there is at least one force opposed to the other forces; for example, the thumb in NTU-Hand V (Fig. 1) should always be a position against the other fingers. The normal of the plane should be chosen to align with direction of the desired manipulation. In planning, we first consider the contact positions for two arbitrary opposing fingers (e.g. thumb and middle finger) such that the two fingers touch to object (e.g. the door handle) and the line segments the two contact points is included in the friction cone [2]. Using this relationship iteratively, each finger's desired contact position on the plane can then be chosen; for finger's whose workspace is outside the selected plane, its desired position is chosen to minimize the closest distance to the convex formed by other fingers. Based on this grasping model, we then choose a desired force such that the sum of forces exerts zero wrench on plane formed by the convex hull of fingertips. Thus, while remaining compliant on the plane, the robot hand can grasp an object by friction forces in the normal direction.

To grasp the object, the thumb is first rotated to the opposite of other four fingers, which fully extends initially. Then the fingers approach the desired contact points according to the planned sequence using impedance control based on joint current control and tactile sensor; they move only the distal phalanx and intermediate phalanges but fix the proximal phalanx. If the plan fails, which might be attributed to overestimated friction coefficient, we increase the normal force at the contact points and solve another force distribution satisfying the above constraints.

We extend the technique above to a full hand-arm system: the robot arm is controlled with position control and the robot hand is controlled with the simplified grasping strategy. Before the operation, the hand-arm planning system generates a reference trajectory for the arm and hand, according to the position and orientation of the object to



HEAD	
D.O.F.	2
RC servo	2
Potential meter	2
LED	8x8x4
Facial expression	8
Control board	5

Arm	
D.O.F.	6x2
Motor	6x2
Encoder	6x2
Control board	6x2

Battery	
Voltage	24V, 48V
Power capacity	8AH, 8AH
Type	$LiFePO_4$
Thermometer	2
Current sensor	6
Voltage sensor	6

Leg	
D.O.F.	6x2
Motor	6x2
Encoder	6x2
Current sensor	6x2
Limit switch	6x2
Control board	6x2

Humanoid Robot	
Name	尼諾(Nino)
Height	145 cm
Weight	68 Kg
D.O.F.	52 個
sensor	112 個

PC	
CPU	Intel i7
RAM	4GB
VGA	Intel® HD Graphics 4000

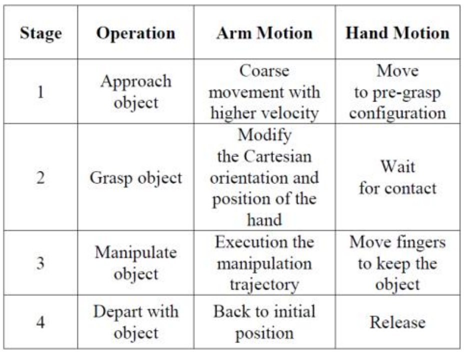
Waist	
D.O.F.	2
Motor	2
Encoder	2
Laser Scanner	1
IMU	1
Control board	2

Hand	
D.O.F.	12x2
Motor	12x2
Encoder	12x2
Potential meter	5x2
Control board	1x2

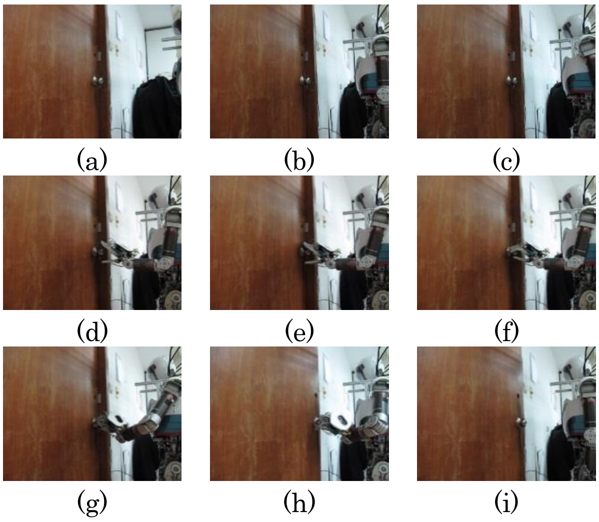
Foot	
Force sensor	1x2
IR sensor	4x2

Figure 1 Humanoid NINO with NTU-Hand V

TABLE I STAGES OF HAND-ARM MOTION



Stage	Operation	Arm Motion	Hand Motion
1	Approach object	Coarse movement with higher velocity	Move to pre-grasp configuration
2	Grasp object	Modify the Cartesian orientation and position of the hand	Wait for contact
3	Manipulate object	Execution the manipulation trajectory	Move fingers to keep the object
4	Depart with object	Back to initial position	Release



(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Figure 2 Experiment results of opening a door

grasp. In effect, the robot arm using inverse kinematics can move the robot hand to the preplanned initial position accurately, and the robot hand can use impedance control to cancel uncertainties. To sum up, we divide the hand-arm operation into four stages: approaching, grasping, manipulating, and departing, as shown in Table I.

B. *Experiments*

Grasping experiments based on these synergies were realized on the humanoid robot NINO with NTU-Hand V in Fig. 1 (145cm; 68kg; 52 degrees of freedom; tactile sensor at fingertips can sense within 4.4N; each finger embeds SEA mechanism to provides additional compliance). The hand was equipped with the anti-slip mats (black parts in Fig. 1) to increase friction on fingertip. The sampling time of this low-level controller is 0.0002 sec.

Door opening is a common application of hand-arm system [3]. In this experiment, the robot was controlled to open a door as an example to show hand-arm system control with errors caused by planning. The flow chart of door-opening follows Table I.

The experimental results are shown in Fig. 2. In the first stage, the robot walked three steps (30cm) up to the 70cm-high door handle, causing little errors for robot arm as shown in Fi.2 (a). Then the robot arm started with an initial state (Fig. 2 (b)), and the arm moved to the handle position (Fig. 2 (c) and (d)). In second stage, the robot hand began to change to the hand state, with the thumb oppose to the other fingers. Because the actually position error brought by walking was unknown without vision feedback, the arm moved to the door until the middle finger’s tactile sensor touched the door as shown in Fig. 2 (e). At that time, hand began to grasp the handle with anti-slip mats equipped on fingertips as shown in Fig. 2 (f). Once hand grasped the knob, the third stage started. The arm trajectory was then generated by inverse kinematics to rotate the handle and open the door, as shown in Fig. 2 (g) and (h). Finally, the hand and arm returned to initial state to finish the task, as shown in Fig. 2 (i).

C. *Conclusion*

In this paper, we focus on grasping control for humanoid NINO with NTU-Hand V to achieve both manipulability and compliance. We propose a simplification on grasping condition to facilitate efficient grasping planning. This desired force is implemented using impedance control based on tactile and current feedback. In extension, we incorporate the hand control into a four-stage hand-arm control. Finally, we show a door-opening experiment to investigate the whole system.

ACKNOWLEDGMENT

This work is partially supported by HIWIN TECHNOLOGIES CORP., R. O. C. under grant number 103-S-A13.

REFERENCES

[1] T. Yoshikawa, "Multifingered robot hands: Control for grasping and manipulation," *Journal of Annual Reviews in Control*, vol. 34, no 2, pp.199-208, 2010.

[2] J.-H. Bae, S.-W. Park, D. Kim, M.-H. Baeg, and S.-R. Oh, "A Grasp Strategy with the Geometric Centroid of a Groped Object Shape Derived from Contact Spots," *IEEE International Conference on Robotics and Automation*, St. Paul, MN, USA, pp. 3798-3804, 2012.

[3] K. Nagatani and S. I. Yuta, "Autonomous Mobile Robot Navigation Including Door Opening Behavior," *in Field and Service Robotics*, pp. 195-202, 1998.