Control Strategy for Simultaneously Inserting Multiple boxes with Dual Arm Manipulator

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Abstract - This paper presents a control strategy for simultaneously inserting multiple cellphone unit boxes into one master box by using a dual arm manipulator. The box insertion strategy is developed based on force control and task planning. The dual arm manipulator knows the approximate location of the unit boxes and master box and smoothly executes its task with error tolerance. This strategy exploits the advantage of dual arm manipulators: the two separate single manipulators interact with each other to complete the task. This study provides the proper control strategy of a dual arm manipulator for a complicated task and demonstrates the efficiency of the dual arm manipulator for rapid task completion.

Keywords – dual arm manipulator, control strategy, force control

1. Introduction

Interest in dual arm manipulators has increased with the public expecting robots that mimic human-like behavior in the near future. Therefore, studying the details of dual-arm manipulators is a natural avenue of research. There are several independent motivations to using a dual arm manipulation setup [1]: the teleoperation setup is similar to that of the human operator; task flexibility and dexterity are increased by using dual arms in a closed kinematic chain; in terms of human–robot interaction (HRI), dual-arm manipulation is more intuitive and similar to human bimanual manipulation; and a dual arm manipulation system is more efficient in environments intended for humans. Dual arm robot systems are starting to be used not only in domestic but also in industrial applications. This trend was initiated to replace and assist human workers using robots without redesigning or modifying the workspace infrastructure [2].

Various types of dual arm robot platforms have been manufactured: e.g., Motoman SDA 10D (Yaskawa) [3], Frida (ABB) [4], and NEXTAGE (Kawada Industries) [5]. These robots are not equipped with mobile devices because their main purpose is to perform repetitive tasks in a structured environment. Dual arm manipulation systems with mobility have been developed to perform tasks in a larger workspace: e.g., PR2 (Willow Garage) [6], Rollin Justin (DLR) [7], uBot-5 (University of Massachusetts Amherst) [8], and TWENDY-ONE (Waseda University) [9] are recently developed wheel-based dual-arm manipulators, and Asimo (Honda) [10], PETMAN (Boston Dynamics) [11], HRP-4 (Advanced Industrial Science and Technology (AIST)) [12], and HUBO2 (Korea Advanced Institute of Science and Technology (KAIST)) [13] are the latest developed bipedal humanoid robots.

Although designing dual arm manipulators to be similar to human arms is a challenging and important process, implementing the proper control strategy is also important. Because the main goal is to apply a dual-arm manipulator in a human environment, many human tasks are performed using the dual arm manipulator: e.g., PR2 used vision-based detection algorithms to demonstrate folding laundry, playing pool with a human, inserting a plug into an outlet, and opening a door [14-16]; and TWENDY-ONE provides physical support to people who need attendant care such as patients and the elderly [9].

This paper suggests a proper control strategy for executing tasks with a dual arm manipulator. In a simulation, multiple cellphone unit boxes were simultaneously inserted into one master box as a demonstration. The box insertion strategy applies force control and task planning. Force control is a suitable method for dual arm manipulators where both arms are in contact with linked objects; the task was planned to replicate dual arm manipulators that are similar to workers on an assembly line.

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2. Control Framework and Task Planning

2.1 Control Framework

The demonstration control framework is based on the virtual spring damper hypothesis. This control is intuitive, and the singularity and null space problem are readily solved. The motion of equation for the manipulator is expressed as

$$\tau_i = -C_0\dot{q} - \xi\Delta q + J_p^T k(\mathbf{x_d} - \mathbf{x}) + J_p^T \mathbf{f_i} + g(q) \quad i = 1,2 \tag{1}$$

where $q = (q_1, q_2, \ldots, q_n)^T \in \Re^n$ denotes a vector of joint positions and $-C_0\dot{q}$ is the joint space damping to prevent null motion. In other words, the joint damping mechanism is optimized in order to execute natural motion and avoid unexpected null motion when the manipulator has a null space. $-\xi\Delta q$ is the muscle tension effect where ξ is the torsional spring gain $(0<\xi\leq 1)$. $-\xi\Delta q$ produces the same motion of each joint when the manipulator has redundancy. The, muscle tension effect term always adapts the manipulator's motion to the direction of the gravitational force in order to increase the energy efficiency [17]. Matrix J_p^T is the Jacobian matrix for analytical robot translation. k is the proportional gain, and $g(q)$ represents the gravity compensation term. Because the robot system is a dual-arm manipulator, i = 1 and 2 represent the right and left manipulators, respectively.

In this control framework, both position and force control are applied because the dual-arm manipulator has to simultaneously grab and lift five unit boxes, as shown in Fig. 1. Here, $\mathbf{f}_i$ from equation (1) are the forces applied to maintain solid contact against each end of the five unit boxes If $\mathbf{f}_i$ are excessive, they will damage the unit boxes; if $\mathbf{f}_i$ are weak, the unit boxes will fall from the dual manipulator during the task. Therefore, impedance control is applied to the force control. The equation for $\mathbf{f}_i$ is expressed by

$$\begin{aligned}&\mathbf{f}_i=(-1)^i k(\mathbf{x}_{d\_i}-\mathbf{x}_i)\\&i=1,2\end{aligned}\tag{2}$$

This equation calculates the force of each arm to apply at the relative positions of each manipulator in order to make the resultant force in the middle box zero: in other words, the two forces have the same magnitude but opposite directions. The suggested impedance control method prevents the boxes from falling during the task even if each manipulator does not grasp the boxes in the desired position.

2.2 Box Insertion Task Planning

Simultaneously inserting multiple unit boxes into one master box is a difficult task because the contact conditions of each box and the manipulator have to be considered. However, humans can execute this task without planning or sensing every box's contact condition. Therefore, planning for the box insertion task is established to replicate human-like motion. Firstly, the dual arm manipulator makes contact with each end of the boxes and presses them together with suitable force. After the dual arm manipulator makes contact with the boxes, it lifts and moves the unit boxes forward to approximately position the boxes on top of the master box. When the boxes are approximately positioned on top of the master box, the dual arm manipulator rotates the boxes. The dual-arm manipulator lowers the boxes and moves sideways to make contact between the lowest unit box edge and the master box edge.

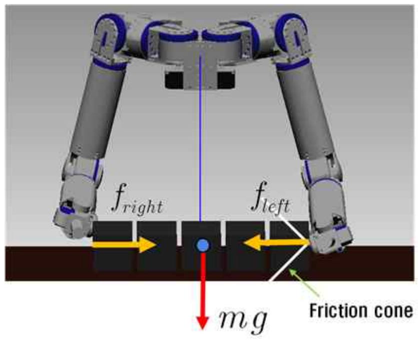

Fig. 1. KITECH dual arm simulation model and the brief concept of applied force control

After the edges between the two boxes make contact, the dual arm manipulator reversely rotates the unit boxes to make them parallel to the master box. When the unit boxes are placed inside the master box, the dual manipulator releases the pressure force on the unit boxes to drop the unit boxes into the master box. Instead of a trajectory being generated for this motion, the point-to-point method is applied here for a more natural motion.

3. Simulation Validation

The developed control strategy and task planning were simulated using a Robotics Lab simulator [18]. Fig. 2 shows the execution result of the box insertion task. The success rate was 95% (for 100 trials). Although the simulation success rate was not perfect, the success rate should increase in the hardware experiment owing to greater friction between the gripper and the box. This paper does not present the hardware verification, but it will be provided in the near future.

4. Conclusion and Discussion

This paper presents a strategy for simultaneously inserting multiple cellphone unit boxes into one master box using a dual arm manipulator in order to demonstrate the efficiency of the dual arm manipulator in rapid and concise task completion. The suggested control strategy and task planning were applied to appropriately control a dual arm manipulator when executing a task by making contact with linked objects. With the suggested control strategy, the dual arm manipulator does not require precise information on the objects in order to complete its task. In other words, the dual arm manipulator can perform tasks with error tolerance.

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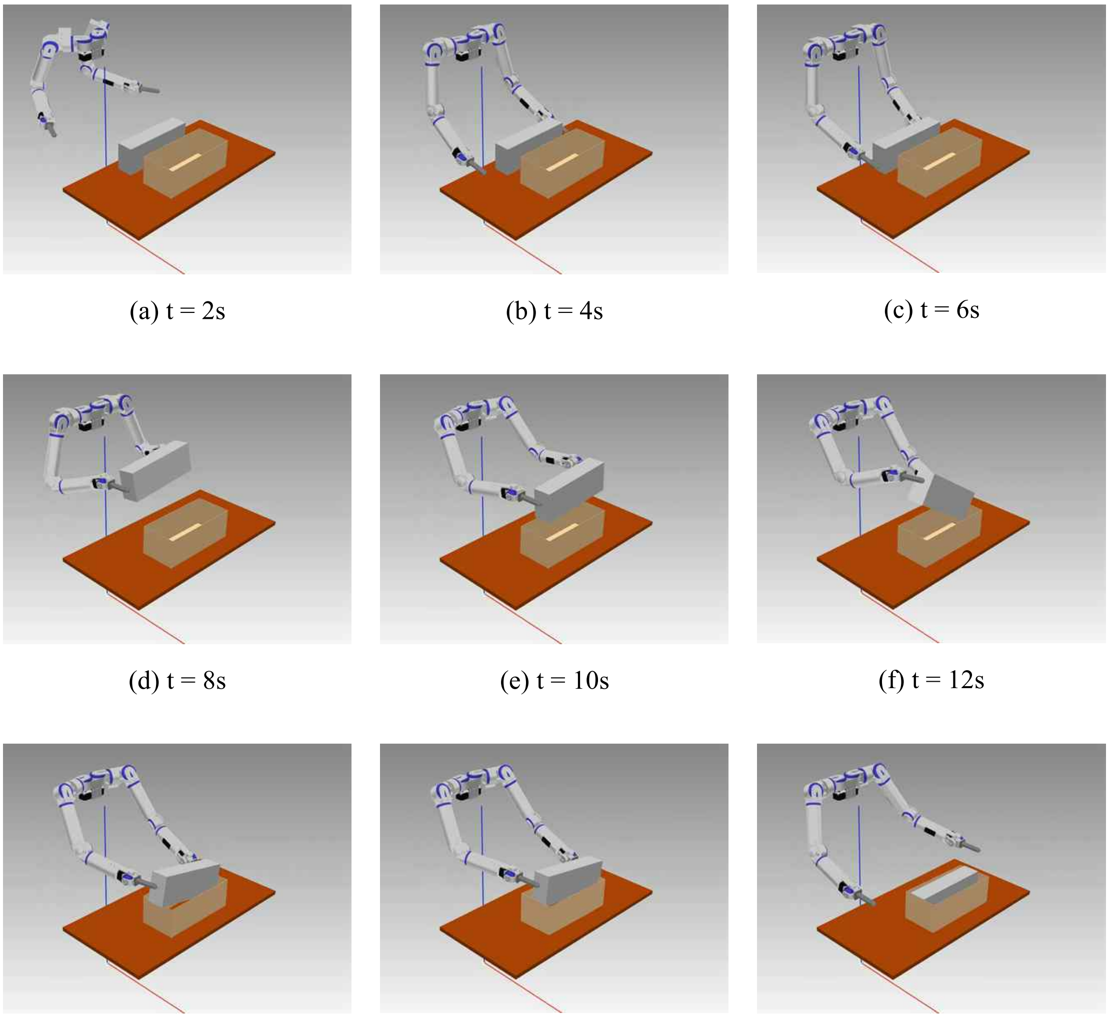

(a) t = 2s (b) t = 4s (c) t = 6s

(d) t = 8s (e) t = 10s (f) t = 12s

(g) t = 14s (h) t = 16s (i) t = 18s

Fig. 2. Simulation Result

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