Application of Caging Manipulation and Compliant Mechanism for a Container Case Hand-over Task

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Abstract

This research aims to realize a container case hand-over task between robots. Although sophisticated cooperative control is essential to avoid destructive internal force in general cooperative transfer task, we propose a geometrical caging strategy which can simplify a hand-over task. To solve a problem of capture region mismatch during caging state transition, the proposed strategy does not utilize additional actuators and sensors but a compliant mechanism whose displacement range can be changed automatically by its configuration. By experiments, it was confirmed that the caging strategy can make the hand-over task drastically easy and robust, and a winch type quasi-compliant mechanism is effective to the problem of capture region mismatch.

I. Introduction

An object hand-over task between multiple robots is more complex and difficult than a handling task by single robot. This is because a sophisticated cooperative control is required to hand-over an object between robots, and if there is any failure the object will be deformed or broken. There were some previous works about cooperative object transferring task between human and a robot[1], [2] or multiple robots[3], [4] . Hirata et al. proposed an idea: "Virtual 3D caster" and actualized leader-follower type smooth cooperative transfer motion[1]. In recent researches, multiple robots cooperative motion without a force sensor were reported[3], [4]. These researches presented some solutions to the problem of co-operative object transfer task which is essential to avoid destructive internal force.

On the other hand, an object hand-over task has a different problem from the cooperative transfer task in terms of a stable state transition. That is to say, the cooperative transfer task has only one state, but hand-over task must realize a smooth and stable state transition from a robot grasping state to another robot grasping state. The transition problem cannot be solved by the previous approaches.

Therefore this paper discusses a strategy for a stable object hand-over task which utilizes caging manipulation and compliant mechanisms. An application target of the proposed strategy is our developing home-use logistical support robot system[5], and the hand-over target is intelligent container (i-Container): the core element of the system (Fig.1, [6]). The goal is to achieve i-Container hand-over task between a container transfer robot[7] and home-use automated container storage/retrieval system[8].

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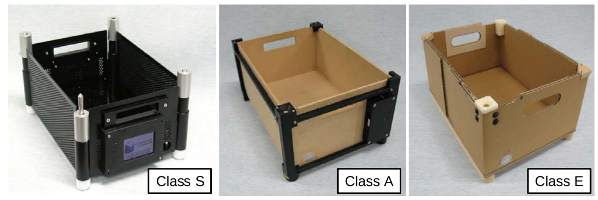


Fig. 1. i-Container family

The framework of this paper is as follows. In Section II, the problem of container hand-over task will be defined and caging manipulation strategy will be discussed. Section III explains the hand-over task installation environment; hand-over target i-Container, a container transfer robot and a home-use automated container storage/retrieval system. Section IV will show the overall task flow and select optimal methods at each process. Section V describes performance experiments of the implemented hand-over task. Section VI is conclusion.

II. Container hand-over task

This section will define difficulty and a problem of an object hand-over task, and propose a caging manipulation strategy to overcome the problem. Next, previous works about caging manipulation will introduced and an optimal caging configuration for the hand-over task will be discussed.

A. Problem definition in an object hand-over task

Firstly we suppose an object hand-over task between Robot A and Robot B, the task is composed of following 3 processes, (1) Stable object manipulation by Robot A alone, (2) Stable cooperative object handling by both Robot A and Robot B, (3) Stable object manipulation by Robot B alone. *Here throwing and catching motion is out of our target, because the target object can be frequently un-stable.

As described in section I, cooperative handling like Fig.2(A) was investigated by some previous works. But transition from cooperative handling to stand alone manipulation like Fig.2(B) cannot be achieved in the framework of previous works and it may be difficult to expand their theory to our target task. Therefore we must consider a strategy that can simplify the hand-over task, and the strategy may be quite different from the previous approaches.

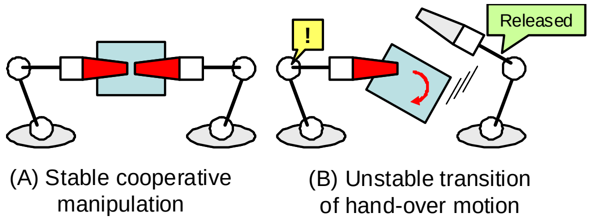


Fig. 2. Difficulty of state transition

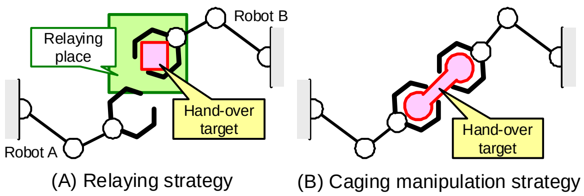


Fig. 3. Conceptual diagram of simplification strategies (Top view)

B. Strategy to simplify the hand-over task

There are two directions to simplify the hand-over task.

1) Relaying strategy (Fig.3(A))
2) Caging manipulation strategy (Fig.3(B))

In the relaying strategy robots execute hand-over motion via a relaying place, and robots perform each pick and place motion. Extra space and accurate object position/posture recognition technologies are essential to apply this strategy, therefore it's not feasible in all cases.

Hence caging manipulation strategy can be an appropriate candidate, in the strategy hand-over target object is constrained flexibly by caging. As flexible constraint conditions, there are several other methods; (1) Frictional support like fork lift (Fig.4), (2) Accurate positioning free grasping mechanism like electro-magnets. But when an accidental contact or collision occurs, an object in the frictional support can change its position and posture and a receiver robot needs to confirm the object state with sophisticated sensor, and positioning free grasping mechanism generally cannot realize robust and stable support. Accordingly we decide to utilize simple and robust geometric constraint.

In the hand-over task, the target object can be applied two different caging conditions. That means the object must have two different structures for caging, one is for a transmitter robot and the other is for a receiver robot.

In general caging strategy can avoid unnecessary internal force. However flexible constraint condition intends difficulty of accurate positioning. So a compliant mechanism becomes a good solution to absorb the position uncertainty in the caging hand-over task.

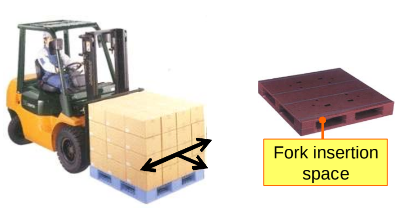


Fig. 4. Freight transporting by forklift

C. Related research of caging

In a set-theoretical definition, caging condition can be describes as equation (1)[9].

$$\begin{cases} C_{free.obj} \neq \emptyset \\ C_{free.obj} \neq q_{obj} \\ C_{free.obj} \cap C_{free.inf} = \emptyset \end{cases} \quad (1)$$

Where $C_{free.obj}$ is a 6 dimensional configuration space of free object motion, q_{obj} is a current object configuration, and $C_{free.inf}$ is free object motion configuration space which is infinitely far away from the current configuration.

That means 1st equation ensures existence of caging state itself, and the 2nd equation ensures existence of capture region. (i.e. this eliminates a situation where an object is fully constraint and immobilize). And the 3rd equation indicates that there is no feasible path from the current configurations to any other free configurations, that means an object cannot go out from the capture region.

As previous works about caging, Rimon and Blake formulated caging condition by Morse theory[10], Pipattanasomporn et al. presented a search and judge algorithms for caging of concave polygonal and polyhedral object[11], [12]. Makita et al. tried to formulate 3 dimensional caging with specific shapes[13]. Wang et al. reported about application of caging (Object Closure) to a multiple robots' cooperative object transfer task.

As the name "Object Closure" represents, caging has much relation to the idea of "Closure", and we can acquire many good concept or guide-line from papers about Closure[14], [15]. For example Nguyen discusses to realize "Force Closure"[15]. In the paper he also analyzed the effectiveness of a soft finger placed at a corner or edges of an object, and referred significance of gravity as if it's a virtual contact point.

However those papers presented good analysis to realize caging, but they supposed no restriction to the $C_{free.obj}$. That is, in the previous caging definition an object in a caging condition can take any position and posture in the capture region. As a general algorithm analysis previous works is sufficient, but it is not feasible to apply the algorithm to a real object manipulation where the position or posture should be kept within a required conditions. For instance a coffee cup can easily be in a caging condition by inserting robot fingers into a ring handle, but for transferring a coffer cup with contents, it is essential to keep horizontal posture of the cup. As a second example, when a robot stores an object (book or container case) to a shelf, direction and posture of the placed object determine the quality of storing (Book title should come to front side).

To summarize, applying caging manipulation to a posture significant object like our target container, following two conditions must be satisfied. (1) Position and posture must be within required specification in its caging capture region. (2) Especially gravity direction may have strict constraint and must be specially cared.

In the next section, a caging framework that can overcome two conditions will be indicated.

D. Geometrical caging manipulation

As a caging framework which can satisfy the above two conditions, we propose a Geometric Object Closure (GOC). Required conditions of GOC are as follows.

Required conditions of GOC

1) An object can move inside a defined capture region. That means, all effect points don't need consistent contact with the object. Such point will be called an effect candidate point.
2) Friction support is not counted as an effect candidate point because of its uncertainty.
3) Gravity direction and non-gravity direction (horizontal) should be discussed in different processes. In the process of gravity direction consideration, gravity itself can be assumed one effect candidate point.
4) For discussion of displacement in 3 different directions (Both positive and negative), one effect candidate point must act (contact) against the displacement within the capture region.
5) For discussion of rotation in 3 different directions (Both positive and negative), two effect candidate points must act (contact) against the rotation within the capture region.

Detailed description of each conditions are as follows. 2nd condition rejects to use frictional force for constraining an object motion. Frictional constraint is used some application like fork lift (Fig.4) and so on. But in these application, some observer or sensors should be installed to monitor the object motion, because transporter acceleration may exceed the frictional constraint. In our research, simplification of an object hand-over task is a policy to realize robust performance, but adoption of such observer or sensors is against the policy. The 3rd condition is based on the general significance of supporting gravity load. The 4th and 5th conditions indicate the caging state in a view of geometrical constraint. That means one reactive force is essential to resist the object displacement in a direction and one facing pair of effect candidate points is essential to resist the moment of object rotation. To correspond the object degree of freedom and constraint conditions, GOC refers Morrow's representation in his "Primitive task" categorization[16].

GOC has two advantages in its deliberation process. (1) Easy drawing process: However set-theoretical definition (Equ. (1)) can define a caging condition very clearly, it is not easy to apply a real application. But GOC is very simple and easy to check while drawing (especially in CAD). (2) Small calculation effort: As described in Wang paper[9], judgment of caging state (or not) isn't easy for arbitrary shape objects. But GOC can be confirmed quickly, because the object position and posture is restricted preliminarily as a capture region, so the number of calculation target configurations is smaller than the one of general caging. Surely Pipattanasomporn proposed a high speed caging judge algorithm about concave polygonal object[11].

On the other hand, it's not feasible to apply GOC framework to general purpose human-like robot hand, so exchange or transformation to a suitable end effecter is essential.

E. State transition between two caging conditions.

As shown in Fig.5, state transition between two different caging conditions must avoid capture region mismatch. That is, some work is essential in a transition from a large capture region caging to a small capture region caging like Fig.5(B).

There are two kinds of solutions to the problem.

1) Position and posture control by additional actuators and sensors.
2) Adoption of quasi-compliant mechanism whose displacement range changes by its configuration.

An example of such quasi-compliant mechanism is a crane winch mechanism (Fig.6). In the system, when the wire is expanded the hung object can move freely, but when wound up the object motion is restricted by a guide structure.

Because the 1st solution need sophisticated recognition and control procedure and those make the system very complex, we selected the 2nd solution which can omit additional actuators and sensors.

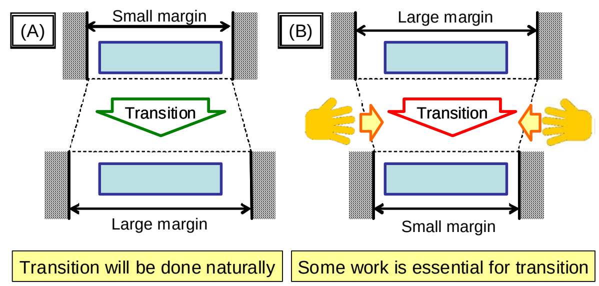


Fig. 5. Capture region mismatch between two caging conditions

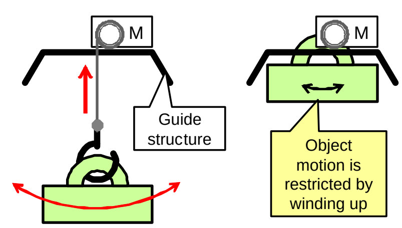


Fig. 6. Margin size variation in a quasi-compliant winch mechanism

III. Robot Design

Firstly this section explains system configuration for the container hand-over task. Secondly overview of each compositional element will be described.

A. System configuration of container hand-over task

Fig.7 shows the system configuration. As described in the section I, the hand-over task is performed between the container transfer robot and the home-use automated storage/retrieval system. The container transfer robot is composed of two components; ceiling mobile component and container handling component.

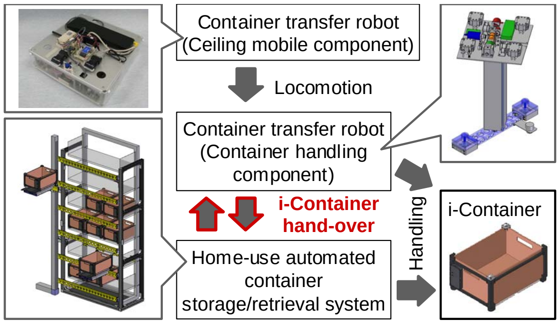


Fig. 7. System configuration of hand-over task

B. Overview of i-Container

Fig.8 shows abstract of i-Container. Functions in detail are described in our previous paper[6], so this section explains geometrical structure of i-Container which is necessary for caging discussion. i-Container has two pin-connection holes for the container transfer robot at top corners. The pin-connection holes are implemented with taper guide, accordingly if connection pins have compliant mechanism the connection motion can be performed even if there is 10[mm] positioning misalignment between the pin and hole. Besides i-Container has fork insertion space at the bottom and has a hook chase at the center bottom for back and forth handling.

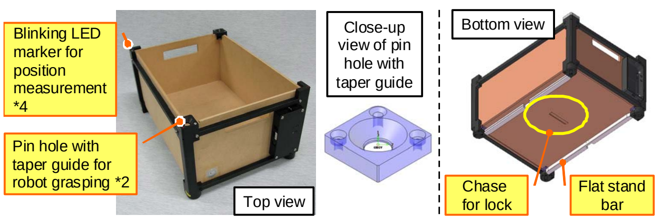


Fig. 8. Overview of intelligent container (Class A)

C. Overview of container transfer robot : ceiling mobile component

Ceiling mobile component utilize permanent magnet inductive traction method[17] as shown in Fig.9. In the method top and bottom robot components are bound by powerful permanent magnets, the upper robot is a differential wheel robot and moves the upper side permanent magnet, the bottom actuation robot is navigated by the upper side robot locomotion. As you can estimate, the upper robot motion is in non-holonomic constraint, so heuristic approach is necessary for accurate position and posture control. In addition, because upper side of the ceiling plate is covered by 2D code (QR code) matrix, the upper robot can estimate its position and posture by reading 2D code. The accuracy of position estimation is under 0.33[mm] and posture estimation is under 0.30[deg] in standard deviation.

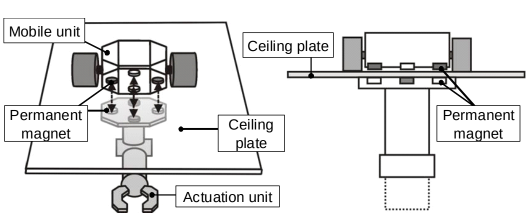


Fig. 9. Permanent magnet inductive traction method

D. Overview of container transfer robot: container handling component

Fig.10 shows overview of handling component. Container handling component is composed of expansion and contraction component (Fig.10 right-top), crane winding component and container manipulation component (Fig.10 bottom). Features of the manipulation component are as follows[18]. (1) Crank connection pin can realize a robust container handling motion only by inserting the connection pin into holes on i-Containers. (2) The manipulation component is installed with two horizontal compliant elements, and each element is composed of 2-axes linear sliders and tension springs. (3) A 2-axes inclination compliant element is settled at the center of body, so it can absorb slope of a target container. (4) When grasping a container with certain load, each compliant elements' functions become low or invalid. Therefore stable transport can be feasible.

Above features of the manipulation component actualize robust container handling motion even if there are 10[mm] position misalignment or 10[deg] inclination mismatch. In Expansion and contraction component(Fig.10 right-top), open steel belt actualized up/down lifting motion, and sliders made of plastic rail and bended metal plate can prevent unintended rotating and twisting motion of the steel belt. When no load is applied, the sliders can prevent unintended deformation of component, but if some external force (ex. human contact) is applied to the component, these can deform and reduce the contact force as shown in Fig.11. By the effect of compliant mechanisms, the posture of the manipulated container does not change so much.

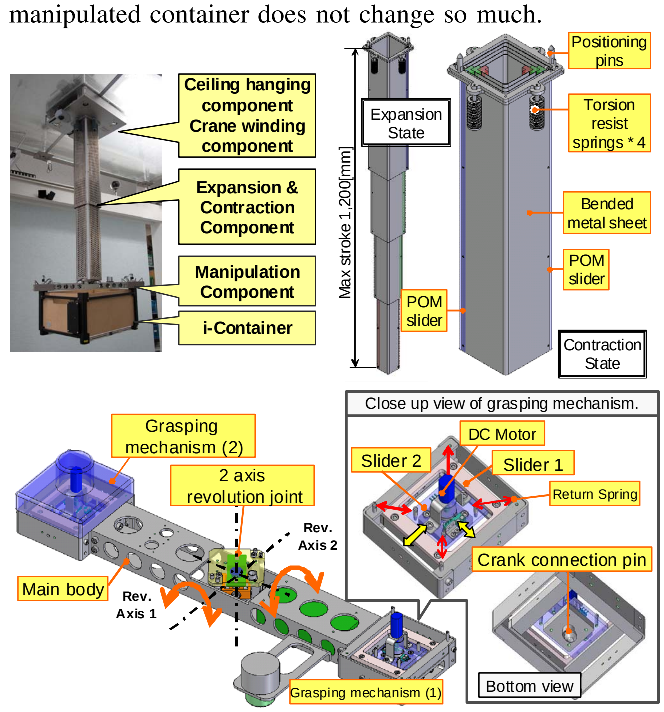


Fig. 10. Abstract of container handling component

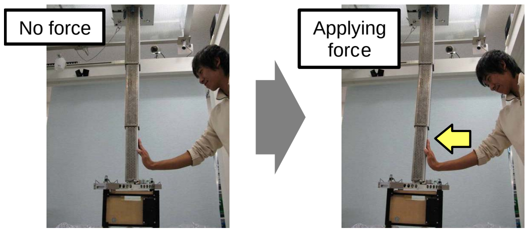


Fig. 11. Deformation of expansion & contraction component

E. Overview of home-use automated container storage/retrieval system

Fig.12 shows overview of the container warehouse. The container warehouse can store multiple i-Containers space-efficiently, and store or retrieve motion can be performed automatically. As a basic structure, the container warehouse utilizes a book shelf in the market, and an expansion frame actualizes the automated container warehouse. By installing horizontal and vertical motions in different structures, the size of drive mechanism is small enough not to invade our living space. In the horizontal transporter, i-Container is handled robustly in two different GOC caging conditions as described in Fig.13, the GOC caging condition is realized by i-Container body itself, a container guide plate, a fork table structure and a lock plate.

Concretely speaking, the flat stand bar of the container and the support structure of the horizontal transporter contacts in surface. Therefore 2 rotation DOF of 2 axes in horizontal plane and 1 displacement DOF of a vertical axis are constrained by taking account of the effect of gravity. In addition, while fork plate insertion motion, the round shape container guides behave like two positioning pins and the open front is restricted by the fork table push plate. That means the rest 2 displacement DOF and 1 rotation DOF was constrained. On the other hand, while lock plate constraint state, the container is restricted by 2 orthogonal parallel guides, this condition also constrains the rest 2 displacement DOF and 1 rotation DOF.

The horizontal transporter recognizes its position by limit switch and the accuracy is also under 1[mm]. Besides the top of horizontal transporter is a bended metal fork table, the bended region can guide the bottom stand bar of i-Container. On the other hand a commercial linear actuator is utilized for the vertical transporter and positioning accuracy is under 1[mm].

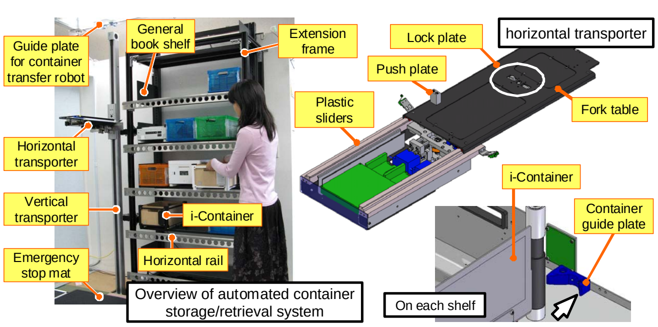


Fig. 12. Abstract of home-use automated container storage/retrieval system

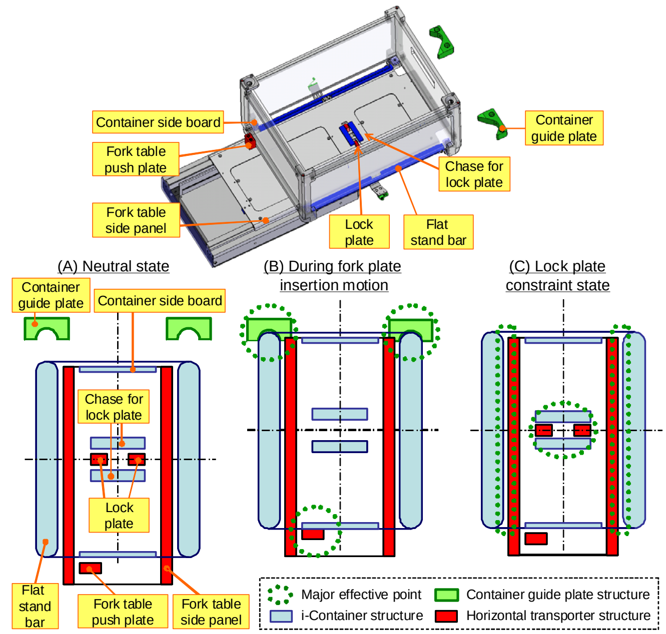


Fig. 13. Caging condition of i-Container and horizontal transporter

F. Caging condition while container hand-over motion

As Fig.12 describes, in the container warehouse i-Container is placed as its handle comes to the front side, and manipulated by inserting fork table at the bottom. As shown in Fig.10, the container transfer robot grasps at the top of i-Container by connecting the crank pins. Consequently the collaborative caging condition while container hand-over motion can be summarized in Fig.14.

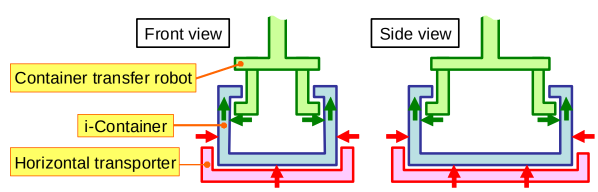


Fig. 14. Caging configuration of container hand-over motion

IV. Implementation of Hand-over Task

To implement the hand-over task, this section explains some discussion points; (1) Hand-over execution place, (2) Horizontal positioning method, (3) Possibility of caging state transition and (4) Vertical positioning method. First of all, abstract of hand-over task flow will shown in Fig.15. There are two directional hand-over tasks as below.

- Retrieve hand-over task: In this task i-Container is delivered from the container warehouse to the container transfer robot.
- Store hand-over task: In this task i-Container is delivered from the container transfer robot to the container warehouse.

A. Hand-over execution place

However there are 3 candidates to execute the container hand-over task, (1) On shelf plate, (2) On horizontal transporter at static rail, (3) On horizontal transporter at movable

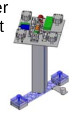
(A) Retrieve hand-over

1	CTR	Move to hand-over point
2	ACSRS	Pick up a container from shelf
3	ACSRS	Move horizontal transporter to hand-over waiting position
4	ACSRS	Actuation of vertical transporter to hand-over execution position
5	CTR	Grasping of container
6	ACSRS	Actuation of vertical transporter to hand-over waiting position
7	CTR	Move to transfer destination

(B) Store hand-over

1	CTR	Move to hand-over point
2	ACSRS	Move horizontal transporter to hand-over waiting position
3	ACSRS	Actuation of vertical transporter to hand-over execution position
4	CTR	Release of container
5	ACSRS	Move horizontal transporter to container placing destination
6	CTR	Move to next target
7	ACSRS	Place a container to a shelf

CTR: Container Transfer Robot



ACSRS: Automated Container Storage Retrieval System

Fig. 15. Container hand-over task flow

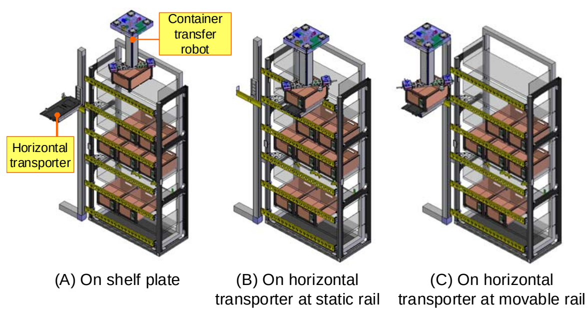


Fig. 16. Comparison of container hand-over place

rail as shown in Fig.16, we selected the 3rd candidate (On horizontal transporter at movable rail). Because the first candidate is based on the relaying strategy and needs extra relaying space, and the second candidate inefficiently needs the horizontal transporter to move on a movable rail after every hand-over task .

B. Horizontal positioning method

There are two different methods to actualize horizontal relative positioning between the container transfer robot and the container warehouse. (1) Utilizing the ceiling mobile component accurate positioning, (2) Leverage of quasi-compliant effect of the permanent magnet inductive traction method.

The container transfer robot can perform accurate positioning based on the 2D code matrix, and the control accuracy is under 1[mm] in position and under 1[deg] in posture. On another front, the ceiling mobile component drives on a plastic surface by urethane rubber wheels, slipping happens frequently and make the positioning capability worse. Therefore leverage of quasi-compliant possibility is effective and efficient. As an concrete implementation, a plastic guide plate are installed which contacts and navigates magnet modules on the container handling component. A margin between the guide plate and those magnet modules are 2[mm] at both side, the margin determines the positioning accuracy.

C. Possibility of caging state transition

To simplify the problem, this research assumes that horizontal surfaces match correctly between container transfer

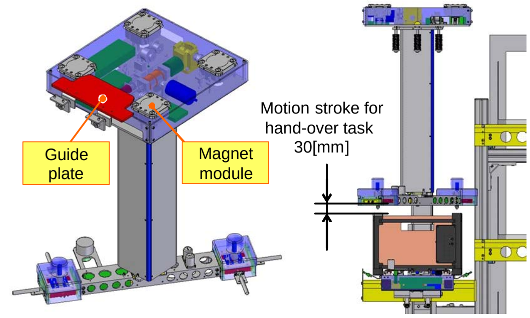


Fig. 17. Guide plate for accurate positioning(Left), Stroke for vertical motion(Right)

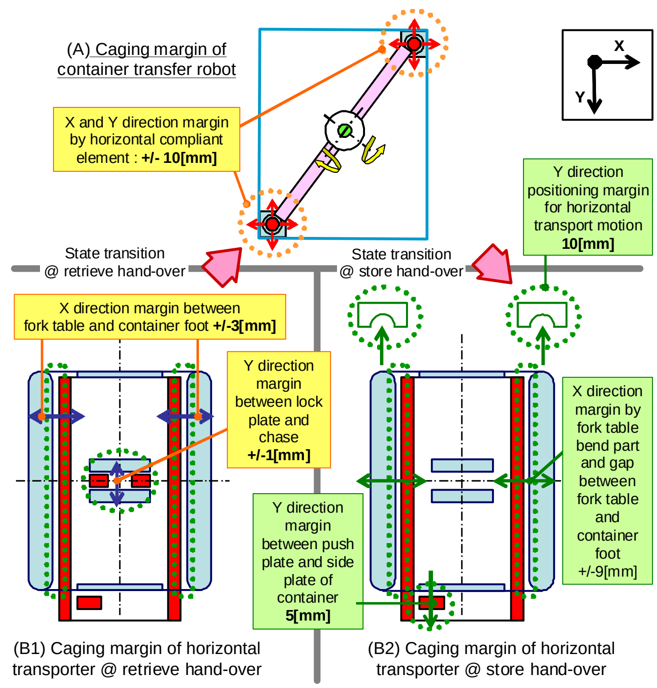


Fig. 18. Caging margins in the container transfer robot and the horizontal transporter

robot and horizontal transporter of container warehouse, therefore our deliberation can be concentrated in a flat plane.

The container transfer robot has horizontal compliant mechanisms, so we must consider a capture region including displacement of those mechanisms. Fig.18 explains the caging capture regions of both container transfer robot and the horizontal transporter. The figure indicates displacement abilities of X, Y axes from base position where the center of i-Container and the center of robots conform completely. As you can see in Fig.18, the capture region size of the container transfer robot is ±10[mm] in both X and Y axes, but in the horizontal transporter the size is X:±3[mm], Y:±1[mm] at retrieve hand-over, or X:±9[mm], Y:-10$\sim$5[mm] at store hand-over. Therefore the capture region of the container transfer robot is broader than the one of horizontal transporter. That means in retrieve hand-over task the caging state transition can be realized easily, whereas the store hand-over task needs some work to modify the mismatch of capture region. This system utilizes the expansion and contraction component (Fig.10, Right-upper) to modify the capture region mismatch. To be more precise, container grasping motion should be executed in the expansion state and container hand-over motion should be in the contraction state. By these processes container lifting-up motion can be utilized to reduce extra capture region. From another viewpoint, the contraction state is more preferable than the expansion state, because the structure is more soft and deformable in the expansion state and may cause undesirable misalignment between grasping mechanisms and a container.

D. Vertical positioning method

After horizontal positioning motion of the container transfer robot, the vertical distance between the tip of manipulation component and the top plate of horizontal transporter is 30[mm] for connection pin insertion as Fig.17(Right) shows.

However both the container transfer robot and the vertical transporter can be actuated to drive the vertical distance, we selected to drive the vertical transporter because height control of the linear actuator is easy and energy saving.

However a failure positioning motion of vertical transporter may destroy the container transfer robot by pushing to the ceiling plate. To avoid the accident, when hand-over task is executed the container transfer robot should leave lift-up for the expansion and contraction. Like this escape method, one directional stiffness of the wire (or belt) winch mechanism is useful to avoid unintended internal force.

V. EXPERIMENTS

This section describes three experiments about container hand-over task. Firstly to confirm the independence of the hand-over capability and positioning capability of the ceiling mobile component, the positioning performance will be tested. Secondly the retrieve hand-over task without capture region mismatch will be examined, and finally the store hand-over task including the mismatch problem will be performed.

A. Experiment of container transfer robot positioning capability

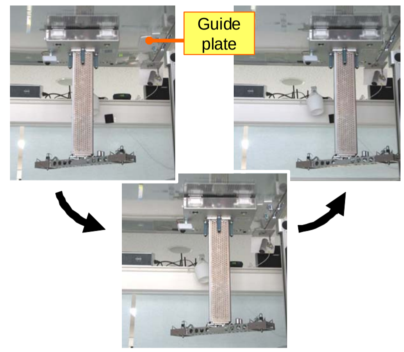
1) Purpose: To confirm positioning performance of the container transfer robot with the guide plate.

2) Method and configuration: The experiment is conducted in following processes.

- The container transfer robot drives to the front of guide plate by rough positioning mode. (Accuracy: position 4[mm], posture 0.5[deg])
- The robot connects to the guide in straight forward mode.
- After the connecting motion ends, the robot measures its position and posture by reading 2D code matrix.

The above processes were repeated 10 times.

3) Result and discussion: Fig.19(left) shows snapshot of the positioning motion to the hand-over point, and Fig.19(right) indicates the result of experiment. As you can see, standard deviation of forward and side position is under 0.5[mm] and the posture deviation is under 0.3[deg], that is quite fine performance of guide plate positioning. The deviation of Y direction where guide plate and magnet module contacts directly is not zero because of position estimation error by 2D code matrix and induction error between the upper and lower magnet modules.



Trial NO.	Stop position/posture Forward [mm]	Side [mm]	Theta [deg]
1	327.7	219.3	93.4
2	328.0	218.5	93.0
3	327.4	218.9	93.2
4	327.3	219.1	92.6
5	328.3	219.2	93.0
6	328.1	218.4	92.8
7	327.7	219.1	92.3
8	328.5	218.2	93.0
9	328.3	218.9	92.9
10	327.6	218.8	92.8
S.D.	**0.4141**	**0.3580**	**0.291**

Fig. 19. Snapshot and result of positioning motion with guide plate

B. Experiment of container retrieve hand-over task

1) Purpose: By simulating some different caging conditions on horizontal transporter of the container warehouse, this experiment will confirm robustness of container retrieve hand-over task.

2) Method and configuration: The set-up is as follows.

- 4 different i-Container positions on the horizontal transporter as presented in Fig.20.
  (X axis offset ±3[mm], Y axis offset ±1[mm])
- Contents of i-Container: Papers (about 2[kg])

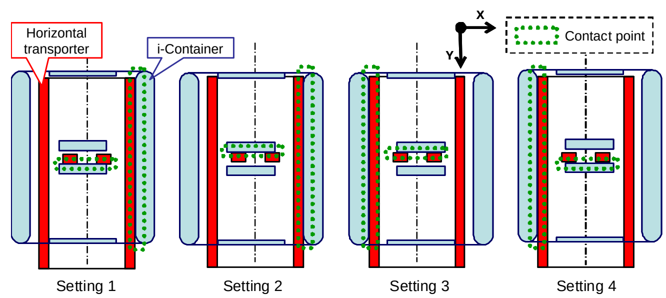


Fig. 20. Initial conditions of retrieve hand-over experiment

3) Result and discussion: Fig.21 shows snapshot of the experiment. It was confirmed that i-Container in all 4 conditions are smoothly handed-over from the container warehouse to the container transfer robot. The result is reasonable because the capture region size of the container transfer robot is broader than the one of horizontal transporter.

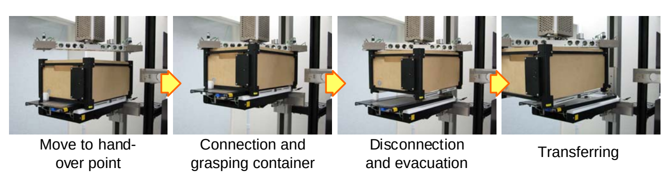


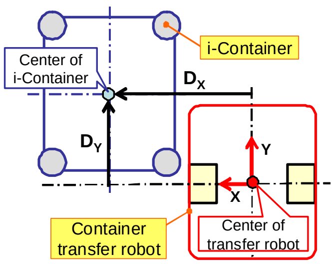
Fig. 21. Sequential images of retrieve hand-over task

C. Experiment of container retrieve hand-over task

1) Purpose: To confirm capability of store hand-over task when a container transfer robot grasps i-Container in different (caging) conditions on a table.

2) Method and configuration: The set-up is as follows.

- Relative position of the container transfer robot and i-Container while grasping: 4 patterns in Fig.22.
- Contents of i-Container: no load or papers (about 2[kg])



NO.	D_X	D_Y
Setting 1	-10	0
Setting 2	0	-10
Setting 3	10	0
Setting 4	0	10

unit [mm]

Fig. 22. Initial conditions of the store hand-over experiment

3) Result and discussion: Fig.23 shows snapshot of the experiment. By the experiment, it was confirmed that the store hand-over task can be performed even if the caging condition is different.

Especially when handing-over i-Container with 2[kg] contents, the delivered i-Container position was almost ideal center of the horizontal transporter. This result can be explained by previous results of compliance effect evaluation experiment[7]. In the experiment, it was confirmed that the lifted-up i-Container position was almost consistent despite of the relative position while the container transfer robot grasps i-Container on a table.

These results represented that the quasi-compliant mechanism (Contraction and expansion component) can modify the capture region mismatch automatically by performing its primary task (Lifting up container).

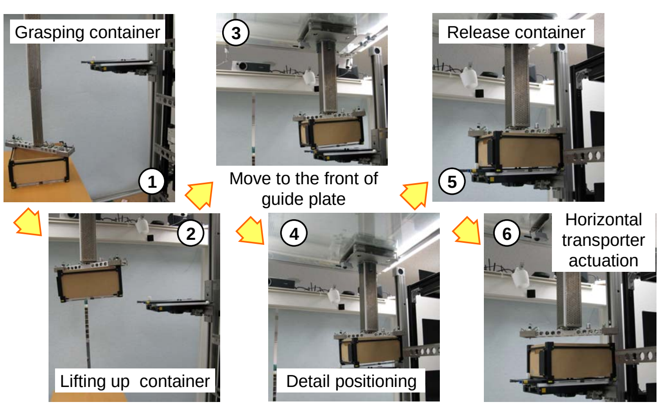


Fig. 23. Sequential images of store hand-over task

VI. Conclusion

This paper aspired to realize a container case hand-over task between robots. Although sophisticated cooperative control was essential to avoid destructive internal force in general cooperative transfer task, we proposed a geometrical caging strategy which can simplify the hand-over task. As an application example, we implemented a container hand-over task and showed the possibility of smooth container retrieve hand-over task by utilizing caging. On another front in container store hand-over task, mismatch of capture region size between the container transfer robot and the container warehouse was an assignment to overcome. To tackle the problem we leveraged a quasi-compliant winch mechanism (expansion and contraction component) to modify automatically the mismatch without any additional actuators and sensors and confirmed the effectiveness of such quasi-compliant mechanism by the experiment.

As described in this paper, (A) Installation of more than 2 different "'caging-able' structures into a target object can simplify a hand-over task, and (B) Fine utilization of a quasi-compliant mechanism can cut off any additional mechanisms for solving capture region mismatch and enables a dual purpose actuation.

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