Grasp Motion Planning for box opening task by multi-fingered hands and arms

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***Abstract*— The aim of our project is to develop a robot to manipulate an object in human environment. In this paper, as a first step, we focus on opening paper box such as tea box, and present a method to plan grasp motion by 2 arms with multi-fingered hands. we propose a task priority based scheme to plan grasping area consistent with whole steps of the given task procedure. Based on the grasping area and the concept of preshape, we derive desired fingertip positions and hand base position and orientation for preshape. Based on the vector field approach, we propose a motion planning method for the planned grasp by multi-fingered hands to avoid any undesired collisions. This method can be applied to regrasping and a motion in which collision is required.**

I. Introduction

Recently, there is much attention on robots executing everyday manipulation in human environment such as opening box, opening package and folding clothes [1]. Multi-fingered hand manipulation is necessary to execute such kind of tasks. However, manipulation by multi-fingered hands and arms is very complicated task for robot. In order to complete a task, the robot has to create a procedure for the task, and to derive motion trajectories for each step to complete the procedure. Our project [2] proposed a method for creating the procedure. First, a data-base for procedures is made inside internet space so that the robot can search a procedure like human uses search-engine. The robot picks up an appropriate procedure or task for the situation, and creates a procedure for the task.

This paper focuses on the task to open (deformable) paper box (for example, tea box) as a first step, and develop a grasp motion planning method for the given task procedure. Table I shows the scenario for the task and the computational problems/issues to be resolved in this paper. Note that this scenario is manually planned. But if embedding our approach to create the procedure, it will be planned by robot system itself.

The main contributions of this paper are as follows: 1. We propose a method to plan grasps by 2 arms with multi-fingered hands, consistent with whole steps of the given task procedure. 2. We propose a method to plan a motion for the planned grasp including grasp for movable object, in which the robot can avoid any undesired collisions while making desired collisions.

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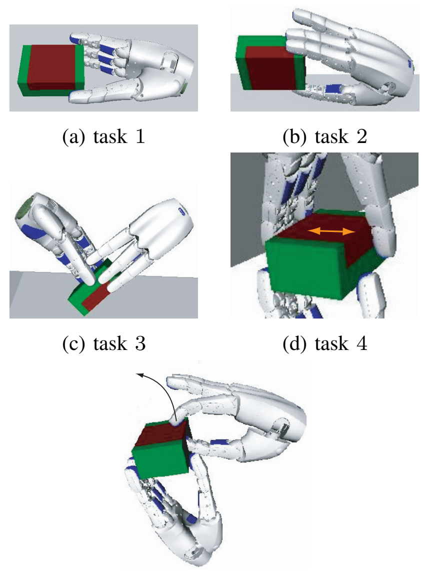


(a) task 1 (b) task 2 (c) task 3 (d) task 4 (e) task 5

Fig. 1. Overview of the task procedure

TABLE I
Task procedure and the problems/issues to be resolved

	Task procedure	Problems/Issues
Fig.1(a)	The robot grasps the paper box on the table by right hand.	Grasp and motion planning
Fig.1(b)	The robot investigates its opening area by camera.	Algorithm for detecting opening area
Fig.1(c)	The robot regrasps the box by left hand to open the box.	Grasp and motion planning to grasp movable object
Fig.1(d)	The robot crashes the box for opening by right hand while holding the box by left hand.	Grasp and motion planning to grasp movable object
Fig.1(e)	The robot opens the box by right hand while holding the box by left hand.	Grasp and motion planning for a motion with collision

When choosing the holding grasps the robot has to take the intended manipulation grasps into account. For example, when holding the box it must hold it such that the opening is still possible, which means that the opening area must not be covered by the holding hand. Also, the box face with the opening area must face the robot.

We propose a priority-based decision scheme to determine the grasping area at every step taking into account the previous, current, and next steps/tasks. The priorities of the grasping task then determine the priorities of the respective grasping areas for both hands and the search area for camera at each step, which we use to arrive at a globally consistent manipulation plan.

We use the concept of *preshape* [3], [4] to make that the hand is in the appropriate configuration when approaching the object, especially, for opening task requiring collision. The effectiveness of using the preshape for this purpose was shown by several researchers [3], [4].

In order to compute the preshape of the hand we take the derived grasping area and construct a *preshaping box (PB)*, which has the faces indicating fingertip positions for preshape and the face indicating palm location. Since the PB has all information for grasping (if roughly speaking), grasp planning problem can be regarded as the problem of where PB should be located for the respective tasks. Using the PB, we derive the desired preshaping positions and the palm position and orientation for the target task. This problem is a nonlinear one. Thus, in order to reduce the computation time, we propose a method to calculate them by a convex problem obtained by applying a linearization to the problem.

Next, in order to make a motion to grasp the target object with the desired state of fingers and hand base (palm), we develop a method of motion planning which distinguishes between desired (contacts) and undesired collisions and avoids the undesired collisions. Human environments often change dynamically. To account for this dynamics, we use a vector field [5] based motion planning strategy. In regrasping, the object is grasped by a hand, and then the object is moved by the holding hand. When opening the box, a certain finger must collide with the box while the other fingers must avoid any collisions. We propose a method which can be applied to a grasp for movable object and a motion with required collision, based on the grouping method of the links and the bodies of the multi-fingered hand. This method can deal with the change of finger configuration and new obstacles which appear during manipulation.

A. Related works

As for detecting opening area, there is a texture-based tracking method [6]. This method can detect the specified texture area and track it if the texture is given.

As for multi-fingered hand, grasping position planning have been researched by many researchers [7]–[9]. On the other hand, there are a few researches for grasp motion planning by arm with multi-fingered hand because it needs not only grasp motion planning but also arm motion planning. In addition, the volume and the workspace of fingers, and the palm position must be considered. Miller et al. proposed a method for the grasp planning [10], using the grasping simulator [11]. Harada et al. [12] proposed a method for hand and arm system to grasp an object based on convex model. Morales et al. [13] proposed a method to plan a grasp using a database for grasping style calculated offline. Berenson et al. [14] proposed a method to grasp a target object in the environment where obstacles exist around the object. However, they didn't take into account *task*.

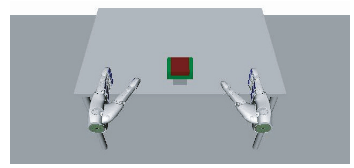


Fig. 2. Initial state

As for plaanning for given task, Prats et al. [4] proposed a method of motion planning for hooking a door. But, the obtained result is limited. There are still many problems to be resolved: for example, planning for other tasks, planning for regrasping. Especially, there is no research about motion planning for task procedure for 2 arms with multi-fingered hands.

As for regrasping, there are many researches [15]–[17], but they took into account only finger(tip) motion.

II. Problem definition

We consider the following task performed by the robot which has 2 arms with multi-fingered hands and camera.

1) The robot grasps a paper box on the table by right hand so that camera can see candidate faces including opening areas (see Fig.1(a)).
2) The robot investigates the box by camera and detects the opening area, rotating the box (see Fig.1(b)).
3) The robot grasps the box by the left hand to hold the box avoiding the opening area so that at the next step, the right hand can open/crash the box. After the grasping, the robot removes the right hand from the box (see Fig.1(c)).
4) The robot crashes (the opening area of) the box by the right hand to open the box while holding the box by the left hand. After crashing, the right hand is removed from the box (see Fig.1(d)).
5) The robot picks the opened area by the right hand to extend the opened area while holding the box by the left hand. Then, the robot extends the opened area by rotating the right hand pinching the opened area (see Fig.1(e)).

Fig.2 shows the initial state. We use SCHUNK Anthropomorphic Hand (SAHhand) [18] which has 4 fingers which, respectively, correspond to thumb, index, middle and ring fingers of human. We assume that the robot knows the opening area is on one of the faces including the longest edge, and around the middle point of the longest edge on the face including the opening area. It means the robot has to search the opening area. In addition, we assume that the robot can use a tracking method such as a texture-based method [6], in order to search the opening area. The motion of the box for searching opening area, and the motion of the hand for crashing and opening the box are assumed to be given.

This paper provides grasp and motion planning for completing this task.

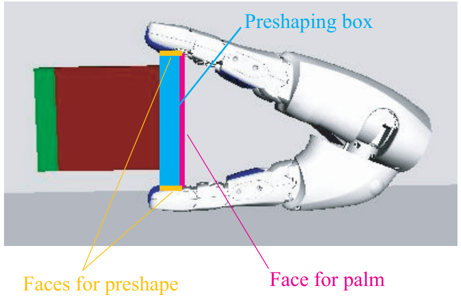


Fig. 3. Grasping style and Preshaping box (PB)

III. GRASP PLANNING

Firstly, we make grasping area according to the task. Then, we make preshaping box (PB) which roughly describes the preshaping positions and palm location. Based on PB, we derive the desired fingertip positions and palm (hand base) position and orientation for preshape.

A. Preshape form

The shape of the object to be grasped is a box. Therefore, the corresponding object model can be expressed by a box. If the shape of the target object is not a box, we will get the object model by splitting the object into several parts, and calculating the minimum sized box for every part which can include the corresponding part like [12]. For the simplicity, we use only one type of grasping style as shown in Fig.3. According to this grasping style, we define the preshaping box (PB) as shown in Fig.3. PB has one face which expresses the preshaping position for thumb finger, its antipodal face which expresses the preshaping positions for the other fingers, and the face which expresses the location of the palm. In this research, we use box shaped PB, but the shape of PB can change to a convex polyhedron according to the grasp style. In addition, the following discussion is the case when using only one type PB, but it can be extended to the case when using several kinds of PB. However, detail discussion is our future work.

B. Grasping region

To find the opening area, the robot must grasp the object so that the camera can see all candidate areas for opening area. If the robot regrasps at the next step, the robot should grasp the object so that the robot can grasp the object by the other hand. Then, different from the case when just only grasping is required, we should find the grasping area consist with not only the current task but also the next and previous tasks. Then, we need consider whole tasks to determine the grasping area for every task. Here, we propose a priority-based decision scheme.

We set the priority of the task as follows.

Task 1: priority 1
Task 2: priority 1
Task 3: priority 2
Task 4: priority 1
Task 5: priority 1

Here, the number of task is associated with the number of the task described at sectionII, and the priority is high if the number of the priority is small. The priority of task 3 is only low since it is not specified, namely how to move for regrasping is not given and we have to plan the motion. Note that here, we manually determine the priority, but it is much better that the given procedure (created by data-base) includes the priority for every task.

Before setting the priority of grasping area and search area for camera, we consider the relationship between the grasping areas for tasks: for example, whether or not the grasping area for the current task is same as that for the previous or the next task. Let $\mathcal{G}_{ri}$ and $\mathcal{G}_{li}$ be, respectively, the grasping areas for right and left hands at task i. Then, according to the task procedure, the relationship can be expressed by

$$\mathcal{G}_{r1} = \mathcal{G}_{r2} = \mathcal{G}_{r3}, \quad \mathcal{G}_{l3} = \mathcal{G}_{l4} = \mathcal{G}_{l5}. \tag{1}$$

Let p_{ri} $(i = 1, \cdots, 5)$ be the priority of (grasping area of) right hand for task i, let p_{li} $(i = 1, \cdots, 5)$ be the priority of (grasping area of) left hand for task i and let p_{ci} $(i = 1, \cdots, 5)$ be the priority of (search area of) camera for task i. If the hand uses the same grasping area as the previous task, we set the priority of the hand equals the priority for the hand for the previous task. Then, from the relationship (1), we get

$$p_{r1} = p_{r2} = p_{r3}, \quad p_{l3} = p_{l4} = p_{l5}. \tag{2}$$

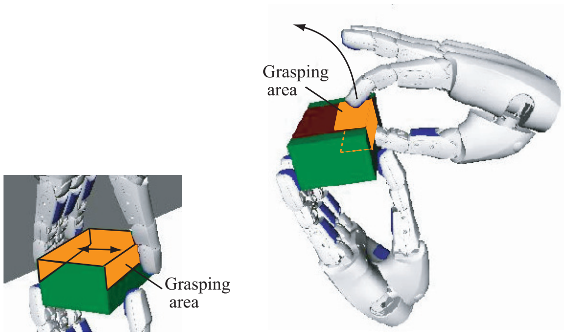
According to the task priority and the relationship (2), we set the priorities of grasping areas for hands and of search area for camera.

If the hand is the main hand to execute the specified task (searching opening area, crashing, and opening) at task i, we set the priority of the hand for task i is the highest. We set the priority so that at every task, the priorities for both hands and camera can have different values from each other. If the priorities for both hands are same (for example, consider task 3), we set the priority of the hand which has the same grasping area at the previous task is higher. Note that if we can not get reasonable grasping areas (for example, nothing), we change the priority or add a new task for regrasping, and recalculate grasping areas. Then, we can get the following priorities of the hands and the camera at every task.

$$\begin{aligned} &p_{r1} = 2, \quad p_{l1} = *, \quad p_{c1} = * \\ &p_{r2} = 2, \quad p_{l2} = *, \quad p_{c2} = 1 \\ &p_{r3} = 2, \quad p_{l3} = 3, \quad p_{c3} = * \\ &p_{r4} = 1, \quad p_{l4} = 3, \quad p_{c4} = * \\ &p_{r5} = 1, \quad p_{l5} = 3, \quad p_{c5} = * \end{aligned} \tag{3}$$

Note that at task 1 and 2, the left hand is not used, and then its priority does not need, and is set to $*$ (which means there is no priority). When we don't need to care about the tracking area for camera to determine grasping area, the priority of the camera is set to $*$.

According to the order of the priority, we determine the grasping area, and search area for camera. Let $\mathcal{G}_{ci}$



(a) task 4 (b) task 5

Fig. 4. Grasping area for the task 4 and 5

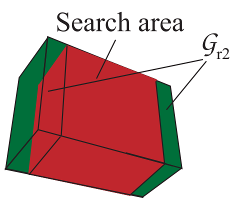


Fig. 5. Area for searching opening area

($i = 1, \cdots, 5$) be the search area for camera at task i. First, we consider $\mathcal{G}_{r4}$, $\mathcal{G}_{r5}$ and $\mathcal{G}_{c2}$, whose corresponding priorities are 1. We define the component for the grasping area, which consists of 3 faces which corresponds to the 2 faces for preshape/grasp and the face for palm of PB shown in Fig.3. We define that the grasping area is union of the components. Since the ways of opening and crashing are given, we determine $\mathcal{G}_{r4}$ and $\mathcal{G}_{r5}$ according to the specified tasks as shown in Fig.4. From the assumption, the candidate faces for the opening area are the faces including the longest edge, and the opening area is around the middle point of the longest edge. If splitting the object model into 3 parts as shown in Fig.5, the central part is the search area.

Next, we consider the grasping area $\mathcal{G}_{r1}$ ($= \mathcal{G}_{r2} = \mathcal{G}_{r3}$) whose corresponding priority is 2. We calculate the union area of $\mathcal{G}_{ci}$ and $\mathcal{G}_{li}$ whose priorities are higher than $\mathcal{G}_{r1}$ at tasks 1, 2, and 3. In this case, the union is $\mathcal{G}_{c2}$. Let $\mathcal{G}_o$ be the whole area of the box. Then, $\mathcal{G}_{r1}$ is given by

$$\mathcal{G}_{r1} = \mathcal{G}_o \cap \mathcal{G}_{c2}^c.$$

As it can be seen from Fig.5, $\mathcal{G}_{r1}$ ($= \mathcal{G}_{r2} = \mathcal{G}_{r3}$) consists of 2 separated parts.

Lastly we consider $\mathcal{G}_{l3}$ ($= \mathcal{G}_{l4} = \mathcal{G}_{l5}$). The corresponding priority p_{l3} ($= p_{l4} = p_{l5}$) is 3. We consider the other areas for the same tasks, whose corresponding priorities are 1 or 2. The union of the areas is given by

$$\mathcal{G}_{ru} = \mathcal{G}_{r3} \cup \mathcal{G}_{r4} \cup \mathcal{G}_{r5}.$$

Then, $\mathcal{G}_{l3}$ is given by

$$\mathcal{G}_{l3} = \mathcal{G}_o \cap \mathcal{G}_{ru}^c.$$

C. Preshaping box

Based on the grasping area, we derive PB. Firstly, we search all possible components (2 faces for preshape/grasp and one face for palm) included in the grasping area. For example, 4 candidate components are included in $\mathcal{G}_{r1}$. For every possible component, we check whether the component is available or not, based on the information about the object state (whether a face is available for grasping or not: for example, if the face contacts with the table, we can not use the face), and the finger constraints (if the maximum distance between thumb fingertip and the other fingertips is smaller than the length between the 2 faces for preshape/grasp, we can not use the corresponding component). Next, we make a box whose 3 faces are the 3 faces of the selected component. After that, we expand the distance between the 2 faces for preshape/grasp so that the hand can not contact with the box at preshape. In this expansion, the sizes of the 2 faces for preshape/grasp do not change while the other faces are extended along the line orthogonal to the 2 faces for preshape/grasp. We define the orientation of PB as follows: z axis is normal of the face for palm, and the direction from palm location to the face is positive. x axis is normal of the faces for preshape, and the direction from the face for thumb finger to the face for the other fingers is negative. Then, the orientation of PB expresses which face for preshape is for thumb finger and which face for preshape is for the other fingers. The position of PB is set to the center of PB. If the number of available PB (or components) is over one, we select either of them, using a criterion such as the distance between the PB and the hand.

For example, the first PB for task 1 is shown in Fig.3. Note that if the length of the edges along z axis of the faces for preshape is so long that the hand can not grasp the box by contacting the fingertips with the center of the faces for preshape, we will shorten the edges.

D. Preshape planning

Based on the PB, we derive desired fingertip positions for preshape. We determine the desired fingertip positions so that the position and orientation of the grasping plane are coincident with the position and orientation of the PB. The grasping plane is defined as follows. Firstly, we consider a triangle or a segment which is the convex hull of the fingertips except for thumb fingertip. We set the position of the grasping plane is the center between the triangle or the segment and the thumb fingertip. x axis is set to the normal vector of the triangle or the direction orthogonal to the segment which goes through the thumb fingertip. y axis is set to the direction from the ring fingertip to the index fingertip. If the line parallel to x axis which goes through the thumb fingertip goes through the inside of the triangle or the segment, force closure grasp can be obtained. If roughly speaking, the grasping plane can expresses the object frame constructed by the fingertips. Note that this discussion is for the grasps with 4 fingers. We determine the number of fingers for grasps according to the size of PB. We can define the grasping plane by a similar way even if the number of fingers for grasps is lower than 4.

Next, we derive hand base (palm) position and orientation, based on the desired fingertip positions for preshape. Let $\boldsymbol{p}_h \in \mathcal{R}^3$, $\boldsymbol{R}_h \in \mathcal{R}^{3\times3}$ be the position and orientation of the hand base, and $\boldsymbol{\phi}_h$ be the three components expressing $\boldsymbol{R}_h$ such as roll, pitch and yaw angles. Let ${}^h\boldsymbol{p}_{fi} \in \mathcal{R}^3$ be the fingertip position of the ith finger with respect to the hand base frame, and $\boldsymbol{p}_{fid}$ be its desired position. Let $\boldsymbol{q}_i$ be the angle vector of the ith finger. Then, the hand state can be expressed by $\boldsymbol{x} = [\boldsymbol{p}_h^T \; \boldsymbol{\phi}_h^T \; \boldsymbol{q}_1^T \; \boldsymbol{q}_2^T \; \boldsymbol{q}_3^T \; \boldsymbol{q}_4^T]^T$. The desired fingertip position for the ith finger is expressed by

$$\boldsymbol{p}_{fid} = \boldsymbol{p}_h + \boldsymbol{R}_h(\boldsymbol{\phi}_h)^h\boldsymbol{p}_{fi} \quad (4)$$

Let $\boldsymbol{x}_n$ be $\boldsymbol{x}$ whose $\boldsymbol{q}_i$ is the current joint angle of ith finger, and whose $\boldsymbol{p}_h$ and $\boldsymbol{\phi}_h$ are the position and orientation of PB. We linearize the relation (4) around the nominal hand state $\boldsymbol{x}_n$. Then, we can get the linear relation ($\boldsymbol{A}_1\delta\boldsymbol{x} = \boldsymbol{b}_1$) with respect to $\delta\boldsymbol{x}$ which expresses the displacements from the nominal state to the state realizing the desired fingertip positions. We also consider the finger constraints such as the limitation of joint angles, which can be expressed by linear inequalities ($\boldsymbol{A}_2\delta\boldsymbol{x} \leq \boldsymbol{b}_2$). Then, we can get $\boldsymbol{x}$ ($= \boldsymbol{x}_n + \delta\boldsymbol{x}$) realizing the desired fingertip positions, solving the following convex quadratic problems.

$$\begin{aligned} &\min_{\delta\boldsymbol{x}} \delta\boldsymbol{x}^T\delta\boldsymbol{x} \\ \text{subject to} \quad &\boldsymbol{A}_1\delta\boldsymbol{x} = \boldsymbol{b}_1 \\ &\boldsymbol{A}_2\delta\boldsymbol{x} \leq \boldsymbol{b}_2 \end{aligned} \quad (5)$$

Note that by solving this problem, we can get the desired joint angles for the desired fingertip positions. Therefore, we can use the desired joint angles for control. Note also that hand base motion corresponds to arm motion. We derive arm motion so that its tip, namely hand base can converge to its desired position and orientation.

IV. Motion planning

Here, we propose a method to plan a motion for the planned grasp by multi-fingered hand, which can avoid any undesired collision, and can applied to regrasping and a motion with collision. For the purpose, we use vector field based motion planning strategy [5]. For every obstacle (with which collision must be avoid), we make a potential function which has high value if the robot is close to the obstacle. We view the potential function as energy. Then, its gradient expresses (reciprocal) force and its direction. It is called vector field. If the robot has several components such as several links, we sum the reciprocal forces for all components. The summed force is the reciprocal force for the robot. On the other hand, we also consider a potential function for the desired state of the robot. The function becomes small monotonously as the robot comes close to its desired state. We view its gradient as attractive force and its direction. Appling the both attractive and repulsive forces to the robot, the robot can reach its desired state avoiding collisions with the obstacle.

When applying this method to our target problem, we have to resolve the following problems:

1) we can not use the summed reciprocal force. For example, let us consider the case when grasping a box by contacting thumb with a certain face and contacting index and middle fingers with its antipodal face. If the distance between the box face and the thumb is almost same as the distance between the box face and the index and the middle fingers, the summed reciprocal force is not zero although it must be zero. Then, the reciprocal force arises the motion in which the thumb collides with the box.
2) According to the reciprocal force, which part of the hand should be moved: finger joints or hand base (palm)?
3) How do we deal with regrasping and a motion with collision?

First, we consider the bounding boxes for all links and palm body of the hand, using CAD data of the hand. SAHhand can be divided into 18 parts. Let b_i ($i = 1, \cdots, 18$) be the corresponding bounding box. We make 3 groups according to the faces of PB; first group $\mathcal{B}_1$ ($= \{b_1\}$) is for palm, second group $\mathcal{B}_2$ ($= \{b_2, \cdots, b_6\}$) is for thumb finger corresponding to the face for thumb for preshape, last group $\mathcal{B}_3$ ($= \{b_7, \cdots, b_{18}\}$) is for the other fingers corresponding to the other face for preshape. We calculate the distance between b_i and the box to be grasped or obstacle. If using L1 norm for distance, we can calculate it by linear programming such as simplex method. Let d_i be the distance. We can get also the point on b_i and the direction (from the point on the box or obstacle to the point on b_i) which give d_i. For every group, we find minimum distance (for example, $\min_{i=2,\cdots,6} d_i$ for $\mathcal{B}_2$), and the corresponding point on b_i and direction which give the minimum distance. We call the point (the nearest point to the box or obstacle) the reciprocal point. Note that the number of the derived minimum distances is not always one. For example, if considering group B_2 and let $d_{\min} = \min_{i=2,\cdots,6} d_i$, then, we regard d_i such that $|d_i - d_{\min}| \leq \epsilon$ where ϵ is a small constant value as minimum distance. We calculate the vector expressing reciprocal force for the group, using the minimum distances and the corresponding directions. Here, let $\boldsymbol{f}_{rij}$ ($j = 1, \cdots, m_i$) be the vector for the group $\mathcal{B}_i$ where m_i denotes the number of the vectors (the number of the derived minimum distances). Let $\boldsymbol{p}_{rij}$ be the corresponding reciprocal point for $\boldsymbol{f}_{rij}$. We define the target component which should move according to the reciprocal force. Joint angles and the frame fixed at hand base (hand base position and orientation) could be the target component. Let $\boldsymbol{G}_{rij}$ be the jacobian matrix expressing the relationship between $\boldsymbol{p}_{rij}$ and the target component. Then, we calculate the reciprocal force with respect to the group $\mathcal{B}_i$ as follows:

$$\sum_{j=1}^{m_i} \boldsymbol{G}_{rij}^T \boldsymbol{f}_{rij}/m_i.$$

This reciprocal force is commensurately applied to the hand with respect to the group $\mathcal{B}_i$. Therefore, we can resolve the first problem described at the initial part of this section. If the target component is the frame fixed at hand base, we sum the reciprocal forces for all the groups (B_1, B_2, B_3), and apply the summed force to the frame. If the target component is joint angles, we consider only the reciprocal force for the group including the joint angles, and apply it to the joint angles.

Next, we consider the second problem. Since the movable region for finger is small, collision avoidance motion by finger angles is limited to small area. Near the box to be grasped, we do not always generate the suitable motion by hand base (palm). Let us consider the aforementioned case when grasping a box by thumb, index and middle fingers, again. If unluckily the distance between the thumb and index or middle finger is smaller than the size of the box, we need to open the fingers each other. This motion can be done by finger angles, but can not be done by moving hand base. Note that it is just an example, and barely happen in succeded planning. Here, we divide the motion into 3 parts: the motion for bringing the hand to near the object, the motion for preshaping, the motion for grasping. At the first motion, the reciprocal force is applied to only hand base. At the second motion, the reciprocal force is applied to not only the hand base but also joint angles. If the hand is very close to its desired state, the reciprocal force is applied to only joint angles. At the third motion, we do not apply any reciprocal forces.

At task 5 (Fig.1 (e)), the thumb finger must collide with the box while the other fingers must avoid collision with the box. We use the aforementioned 3 groups $\mathcal{B}_i$ $(i = 1, 2, 3)$. The group for thumb finger $\mathcal{B}_2$ can be regarded as the group which will collide with the box. The other groups can be regarded as the group which must avoid any collisions. At the first motion, we use the same way as the way mentioned the above. At the second motion, we take the following way: Before collision (between the thumb and the box), we apply the reciprocal forces to the hand base and the joint angles contained at the group $\mathcal{B}_3$. After collision, we apply the reciprocal force to the joint angles contained at the group $\mathcal{B}_3$. Then, the robot can move so that the thumb finger collides with the box while the other fingers and bodies can avoid any collisions.

We generate the motion for the hand holding the box such that the box face with the opening area can face the robot. If the holding hand moves, the box also moves. Then, if the other hand will grasp the moveable box, the motion for the (other) hand must be consistent with the box motion. We can get the command (motion) information for the hand holding the box, since it is done by the robot itself. Using this information, we derive the motion command for the hand which will grasp the (movable) box. We add the force compensating for the attract and reciprocal forces for the hand holding box to the attract and reciprocal forces for the other hand which will grasp the box. Then, we can get suitable motion for the hand which will grasp the box; the robot moves to grasp a moveable box, avoiding undesired collisions with it.

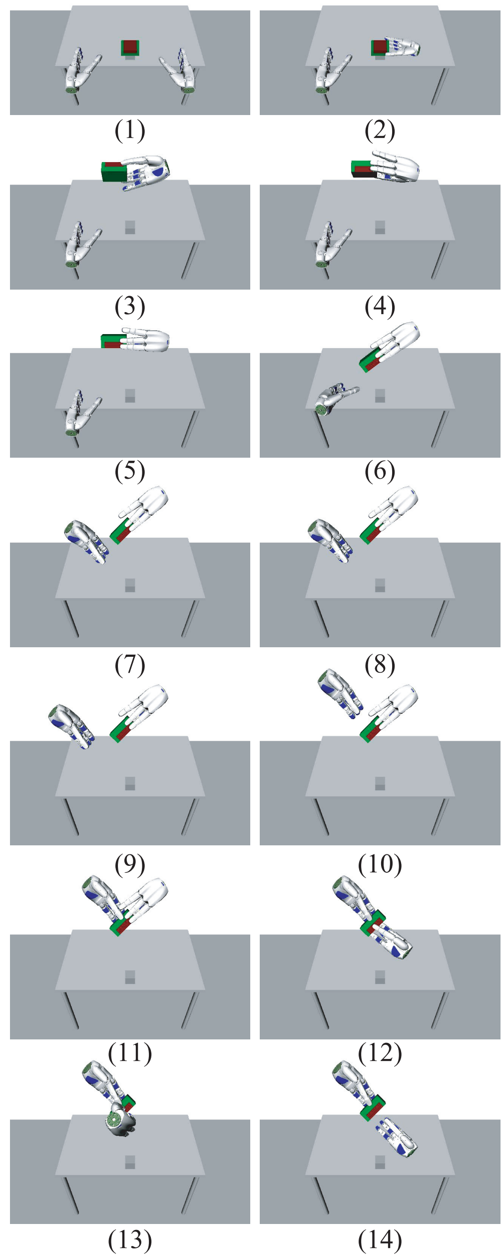


Fig. 6. Box opening task

Lastly, grasping is done by moving the fingers in the direction of internal forces. Then, we can get the grasp motion which do not affect (arise) the motion of the box. The amount of finger motion for grasping without crushing is determined according to real experimental results. We check the force magnitude by torque sensors attached with every joint to avid crashing. On the other hand, if crashing is needed, we also determine the amount of finger motion by experimental results.

V. Numerical Example

To conform the validity of our approach, we show a numerical example. We consider the system shown in Fig.2. We don't use a specified arm. The main program is written by C++ language. For the simulation, we use openrave [19]. At the openrave environment, we get the information about joint angles, hand base state (position and orientation) and object state (position and orientation). As for the object state, we assume that we can get the object state by camera. Before finding the opening area, the information from the camera does not have the information about the opening area. After finding the opening area, the information from the camera includes the information about where the opening area is.

Firstly, we send the information to the main program. Based on the information, the main program calculates the commands for the finger joints and the hand base state, and send them to the openrave. Repeating this way, we simulated. We use yrap program [20] for the communication. We check collisions at the openrave environment.

Fig.6 shows the task for opening box. The number shows the order of the task. (1) and (2) show task 1, and (2)∼(5) show task 2. (5)∼(11) show task 3. Here we show several views to show the collision avoidance motion and how to deal with the movable target box. (5)∼(7) show how to deal with the movable target box. (7)∼(10) show the collision avoidance motion. (5)∼(10) show the first motion part described at section IV while (10) and (11) show the second motion part. As for the third motion part for grasping, refer to see (12) which shows the left hand holds the box. (11) and (12) show task 4, (12)∼(14) show task 5. We do not show deformed (opened) state of the box at (14), but (14) shows the appropriate hand configuration. The configuration for grasping or preshaping is also shown in Fig.1.

VI. Conclusion

This paper presented a method of grasp motion planning for 2 arms with multi-fingered hands for opening paper box. we proposed a task priority based scheme to plan grasping area consistent with whole steps of the given task procedure. Based on the concept of preshape, we took the planned grasping area and derived desired fingertip positions and hand base position and orientation for preshape. Based on the vector field approach, we proposed a method to plan a motion for the planned grasp by multi-fingered hands, which can avoid any undesired collisions. This method can be applied to regrasping and a motion with collision.

This is the first step of our goal. Our goal is to develop a robot system which can autonomously manipulate an object in human environment. Then, we have many further problems. For example, the robot is asked to open the box. First of all, the robot must investigate/explore the environment by sensors, and find and recognize where the target object is and where the obstacles are. It is still difficult problem in the environment including many uncertainties. In addition, if there are several (same) boxes, the robot has to know the intention of the commander and select the box. Next, according to the situation, the robot has to make a procedure for the task. After that, this approach can be applied. To deal with other everyday tasks, we need to extend this approach to more generalized one. Furthermore, we need to combine the methods to resolve these problems. These are our furture works.

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