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Motion Planning for Fetch-and-Give Task using Wagon and Service Robot

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***Abstract*— Daily life assistance for elderly individuals in hospitals and care facilities is one of the most urgent and promising applications for service robots. Especially, a fetch-and-give task is a frequent and fundamental task for service robots to assist elderlys daily life. In hospitals and care facilities, this task is often performed with a movable platform such as a wagon or a cart to carry and deliver a large amount of objects at once. Thus the navigation and control of not only a service robot but also a movable platform must be planned safely. In addition, a robot motion planning to hand over an object to a person safely and comfortably according to his/her posture is also an important problem in this task, however this has not been discussed so much. In this work, we present a coordinate motion planning technique for a fetch-and-give task using a wagon and a service robot. Handover motion is also planned by considering the manipulability of both a robot and a person. Experiments of a fetch-and-give task using a service robot are successfully carried out.**

I. INTRODUCTION

The manpower shortage in hospitals and elderly care facilities is a common problem in an aging society. Care workers have to perform various of jobs in a short period ranging from a light task such as picking-up an object from a floor to a highly-specialized medical treatment. If a service robot can perform several simple tasks instead, even if these are light and simple tasks, it is quite helpful for them since they can concentrate other complex jobs in the meantime.

A fetch-and-give task is one of representative light tasks in assistance of elderly's daily life. In hospitals and care facilities, this task is sometimes performed with a movable platform such as a wagon or a cart to carry and deliver a large amount of objects at once. Thus if a service robot performs this task, the navigation and control of not only a service robot but also a movable platform must be planned.

The robot must know the location of the user to follow him/her in order to deliver an object requested by a user. We have been developing the informationally structured platform in which distributed sensors and actuators are installed in a room to provide a service task by a service robot [1], [2]. On this platform, for example, objects such as books, pens, pet bottles, chairs, and desks are detected by embedded sensors, also floor sensing system can measure the poses of human and robot using a laser range finder located on a floor, and all the data are stored in the database. A service robot is able to obtain necessary information to perform a service task on-demand from the database [3].

In this paper, we present a coordinate motion planning technique for a fetch-and-give task using a wagon and a service robot in the informationally structured platform. When the robot hands over the object to the user, both the handover position of the object and the base position of the robot must be planned according to the user's posture. This paper proposes a handover motion which is planned by considering the manipulability of both a robot and a person. We carried out several experiments for a fetch-and-give task using a service robot in the informationally structured platform and verified the validity of the proposed technique.

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II. RELATED WORK

We have been developing an informationally structured environment referred to as the Town Management System (TMS) using distributed sensors embedded in the environment [1]. Recently, we extend the TMS and develop a new Town Management System called the ROS-TMS [4]. The ROS-TMS is an architecture which connects various sensors distributed in an environment such as laser range finders, cameras, RFID tag readers, or proximity sensors, various robots, and a database based on Robot Operating System (ROS) [5]. The ROS-TMS is able to acquire, store, and analyze environmental information, and plan and control robot motion adaptively.

The problem of handing over an object between a human and a robot has been studied in human-robot interaction (HRI) [6]–[14]. [6] introduced the concept of Mightability Maps based on visibility and reachability of the agents for tasks in Human-Robot interaction. [11] presented a novel cost-space planning approach for computing human-aware motions considering the cost of distance, visibility and reachability. In particular, the work that is closest to ours is the one by Dehais et al. [10]. In their study, physiological and subjective evaluation for a handing over task was presented. The performance of hand-over tasks were evaluated according to three criteria: legibility, safety and physical comfort. These criteria are represented as fields of cost functions mapped around the human to generate ergonomic hand-over motions. [9] introduced specific poses for handing over objects to humans. [14] presented an affordance-sensitive system for direct robot to human object handover using fixed manipulator. Although their approach is similar to our approach, we consider the additional criteria, that is, the

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manipulability of both a robot and a human for a comfortable and safely fetch-and-give task with a movable wagon.

The problem of pushing carts using robots has been reported in many studies so far [15]–[21]. The earlier studies in pushing a cart were reported using a single manipulator mounted on a mobile base [15], [16]. In these systems, a single manipulator held a cart at a single point, and the planning of effector force to produce desired trajectories was discussed. The problem of towing a trailer has also been discussed as an application of a mobile manipulator and a cart [17]. This work is close to the approach in this paper, however, a pivot point using a cart is placed in front of the robot in our technique.

The applications for pushing mobile objects has been presented for several humanoid robots, such as ASIMO, HRP-2 and H7. Stilman et al. [18] presented a planner that takes advantage of the underlying navigation C-space to construct real-time solution for NAMO (Navigation Among Movable Obstacles) problems. Nozawa et al. [19], [21] presented a motion control technique to push a wheelchair by a humanoid robot using dual-arm force control. They adopted a zero-moment-point (ZMP) offset approach to stabilize a body motion with a mobile object.

The work that is closest to ours is the one by Scholz et al. They provided a solution for real time navigation in a cluttered indoor environment using 3D sensing [20]. Though the first attempt with the cart by Tan et al. [15], [16] was limited to simple paths using an open-loop controller, Scholz et al. proposed the solution to execute smooth and arbitrary trajectories in a closed loop controller with PR2.

Many previous works focus on the navigation and control problems for moveable objects. On the other hand, we consider the problem including handing over an object to a human using a wagon, and propose a total motion planning technique for a fetch-and-give task with a wagon using the ROS-TMS architecture.

III. Motion Planning

Motion planning consists of sub-planning, integration, and evaluation of the planning described below to implement the fetch-and-give task. Each planning, integration, and evaluation process uses environment data obtained from the database in ROS-TMS. Moreover, actions that integrate overall planning are obtained from a combination of various individual planning threads. The integration method is considered to be not only efficient but also safe in places such as hospitals and elderly care houses. The output consists of a series of actions that can be executed efficiently and safely.

1) Grasp planning to grip a wagon
2) Position planning for object delivery
3) Movement path planning
4) Path planning for wagons
5) Integration of planning
6) Evaluation of efficiency and safety

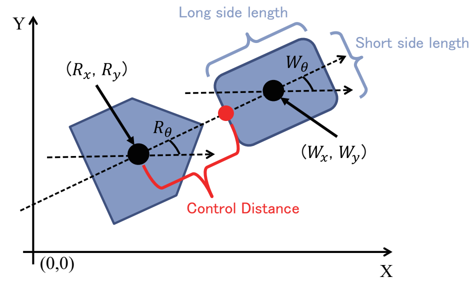

Fig. 1. Base position of the robot at the time of gripping the wagon ($i = 2$)

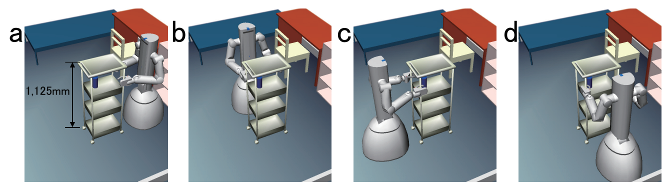

Fig. 2. Candidate points for wagon gripping position: (a) i=0, (b) i=1, (c) i=2, (d) i=3.

A. Grasp planning to grasp a wagon

In order to push a wagon, the robot needs to grasp the wagon at first. There is an infinite number of base positions that the robot can have relative to a wagon that the robot must grip. However, a robot can push a wagon in a stable manner if the robot grasps the wagon from two poles positioned on its sides. Thus, the number of base position options for the robot with respect to the wagon is reduced to four (i) as shown in Fig. 2. The position and orientation of the wagon, as well as its size, is managed using the database in ROS-TMS. Using this information, it is possible to determine the correct relative position. This provides the distance, i.e., the control distance (CD), between the robot and the wagon when the robot is actually grasping the wagon. Based on the wagon direction when the robot is grasping its long side, valid candidate points can be determined using Eqs. (1) through (3) below ($i = 0, 1, 2, 3$). Here, R represents the robot, and W represents the wagon. Subscripts x, y, and θ represent the corresponding x-coordinate, y-coordinate, and posture (rotation of the z-axis). Figure 1 shows the positional relationship between the robot and the wagon, given $i = 2$. Moreover, Fig. 2 shows the wagon gripping position as a 3D model, given $W_\theta = 0$.

$$R_{x_i} = W_x + (\frac{W_{\text{size}_i}}{2} + CD)\cos(W_\theta + \frac{i}{2}\pi) \tag{1}$$

$$R_{y_i} = W_y + (\frac{W_{\text{size}_i}}{2} + CD)\sin(W_\theta + \frac{i}{2}\pi) \tag{2}$$

$$R_{\theta_i} = W_\theta + \pi + \frac{i}{2}\pi \tag{3}$$

$$W_{\text{size}_i} = \begin{cases} \text{length of the wagon's long side} & (i = 0, 2) \\ \text{length of the wagon's short side} & (i = 1, 3) \end{cases}$$

B. Manipulability map for position planning

In order to hand over object to a person, it is necessary to plan both the position of the object to be delivered and the base position of the robot according to the person's position. Using manipulability as an indicator for this planning, the system plans the position of the object relative to the base position. Manipulability is represented by the degree to which hands/fingers can move when each joint angle is changed. When trying to deliver object in postures with high manipulability, it is easier to modify the motion, even when small gaps exist between the robot and the person. Since it is difficult to know the exact position of the person, or to operate the robot without errors, a method that deals with these gaps is indispensable. The velocity vector $\boldsymbol{v}$ corresponds to the position of hands, and $\boldsymbol{q}$ is the joint angle vector. In addition, we assume the high manipulability of the arm of the person makes him more comfortable for grasping object. Their relation is represented in Eqs. 4 and 5.

$$\boldsymbol{v} = \boldsymbol{J}(\boldsymbol{q})\dot{\boldsymbol{q}} \tag{4}$$

$$\omega = \sqrt{\det \boldsymbol{J}(\boldsymbol{q})\boldsymbol{J}^T(\boldsymbol{q})} \tag{5}$$

If the arm has a redundant degree of freedom, an infinite number of joint angle vectors corresponds to just one hand position. Therefore, when solving the inverse kinematics of this issue, we calculate the posture that represents the highest manipulability within the range of possible joint angle movements. The planning procedure for the position of object and the position of robots using manipulability is as follows:

1) The system maps the manipulability that corresponds to the robots and each person on the local coordinate system.
2) Both manipulability maps are integrated, and the position of object is determined.
3) Based on the position of object, the base position of the robot is determined.

We set the robot as the origin of the robot coordinate system, assuming the frontal direction as the x-axis and the lateral direction as the y-axis. At each position on the XY plane, the manipulability is mapped for the situation in which objects are being carried by hand, as shown in Fig. 3a. This mapping is superimposed along the z-axis, which is the height direction, as shown in Fig. 3b. Thus, we create a three-dimensional manipulability map relative to the coordinate system of the robot. Similarly, we are also able to create a manipulability map for persons in Fig. 3b.

C. Position planning for object delivery

The next step is to determine, using the manipulability map, the position of the object that are about to be delivered. As shown in Fig. 4a, we take the maximum manipulability value according to each height, and retain the XY coordinates of each local coordinate system. These coordinates represent the relationship between the base position and the positions

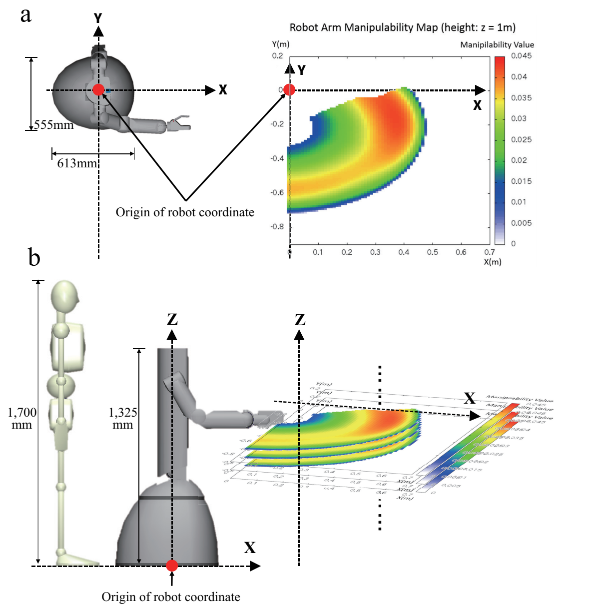

Fig. 3. Manipulability map for the robot: (a) 2D manipulability map for robot, (b) 3D manipulability map for robot.

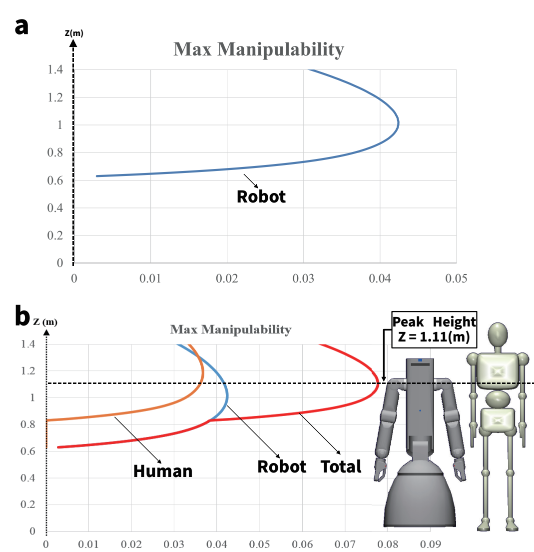

Fig. 4. Maximum value of manipulability: (a) maximum value of robot manipulability, (b) merge results for manipulability.

of the hands. We apply the same process to the coordinates of persons, thus superimposing the manipulability maps for robots and people, as shown in Fig. 4b. In doing so, the z-axis values on the manipulability map can be compensated for by using the face of the target person as a reference and synthesizing this data to suit the corresponding conditions of the person, for example, if the person is standing or sitting. As a result, the height value z in the absolute coordinate system used when delivering object corresponds to the height of the sum of the maximum values of the manipulability.

According to the calculated height on the manipulability map for a person, the system requests the absolute coordinates of the object to be delivered, using the previously retained relative coordinates of the hands. It is also possible to use this position as a reference point to request the position of the object by fitting the relative coordinates. According to the aforementioned procedure, we can determine the unique position of the object that are about to be delivered. As the final step, the base position of the robot is determined in order to hold out the object to their previously calculated position. According to the manipulability map that corresponds to the height of a specific object, the system retrieves the relationship between the positions of hands and the base position. Using the position of the object as a reference point, the robot is able to hold the object out to any determined position if the base position meets the criteria of this relationship.

Consequently, at the time of delivery, points on the circumference of the position of the object are determined to be candidate points on the absolute coordinate system of the base position. Considering all of the prospect points of the circumference, the following action planning, for which the system extracts multiple candidate points, is redundant. The best approach is to split the circumference n time, fetch a representative point out of each sector after the split, and limit the number of candidate points. After that, the obtained representative points are evaluated as in Eq. (6), while placing special emphasis on safety.

$$E_{give\_obj\_pos} = View + D_{human} + D_{obs} \tag{6}$$

Here, $View$ is a boolean value that represents whether the robot enters the field of vision of the target person. If it is inside the field of vision, then $View$ is 1, otherwise $View$ is 0. This calculation is necessary because if the robot can enter the field of vision of the target person, then the robot can be operated more easily and the risk of unexpected contact with the robot is also reduced. In the above equation, D_{human} represents the distance to the target person, and D_{obs} represents the distance to the nearest obstacle. In order to reduce the risk of contact with the target person or an obstacle, the positions that represent the largest distance to the target person or obstacles are valued higher.

If all the candidate points on a given circumference sector result in contact with an obstacle, then the representative points of that sector are not selected. According to the aforementioned process, the base position of the robot is planned based on the position of the requested object. The results for the case in which a person is standing still are shown in Figs. 5a through 5c, and the results for the case in which a person is sitting by a table are shown for Figs. 5d and 5e. The corresponding evaluation results are shown in Table I.

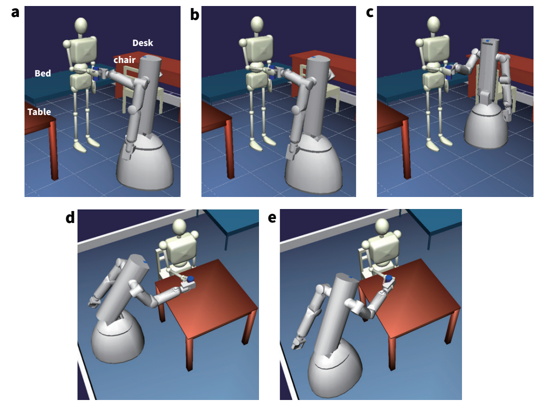

Fig. 5. Object delivery position candidates

TABLE I
EVALUATION OF CANDIDATE OBJECT DELIVERY POSITIONS

Position	a	b	c	d	e
View	1.00	1.00	0.00	0.00	1.00
D_{human}	1.08	1.14	0.78	0.81	0.97
D_{obs}	1.00	0.85	0.52	0.44	0.50
E_{value}	3.08	2.99	1.30	1.25	2.47

D. Movement path planning

1) Path planning for robots: Path planning for robots that serve in a general living environment requires a high degree of safety, which can be achieved by lowering the probability of contact with persons. However, for robots that push wagons, the parameter space that uniquely defines this state has a maximum of six dimensions, that is, position (x, y) and posture (θ) of a robot and a wagon, and planning a path that represents the highest safety values in such a space is time consuming. Thus, we require a method that produces a trajectory with a high degree of safety, but at the same time requires a short processing time. As such, we use a voronoi map, as shown in Fig. 6.

2) Path planning for wagons: In order to be able to plan high-safety trajectories for wagons in real time, we need to reduce the dimensions of the path search space. The parameters that uniquely describe the state of a wagon pushing robot can have a maximum of six dimensions, but in reality the range in which the robot can operate the wagon is more limited. As such, for the case in which a robot is pushing a wagon, we set up a control point, as shown in Fig. 7, which fixes the relative positional relationship of the robot with the control point. The operation of the robot is assumed to change in terms of the relative orientation (W_θ) of the wagon with respect to the robot.

In addition, the range of relative positions is also limited. Accordingly, wagon-pushing robots are presented in just four dimensions, which shortens the search time for the wagon path planning. Path planning for wagon-pushing robots uses the above-mentioned basic path and is executed as follows:

1) The start and end points are established.
2) The path for each robot along the basic path is planned.
3) According to each point on the path estimated in step 2, the position of the wagon control point is determined considering the manner in which the position of the wagon control point fits the relationship with the robot position.

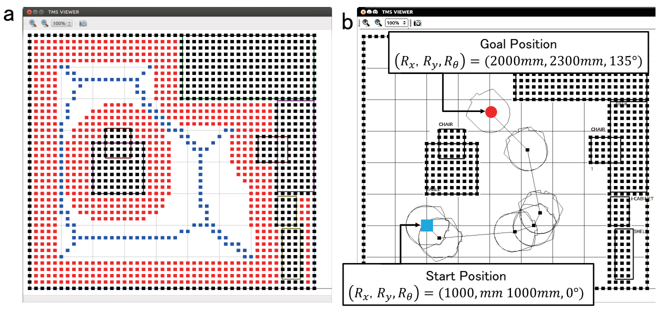

Fig. 6. Voronoi map and movement path: (a) collision area (red) and basic path (blue), (b) robot movement path.

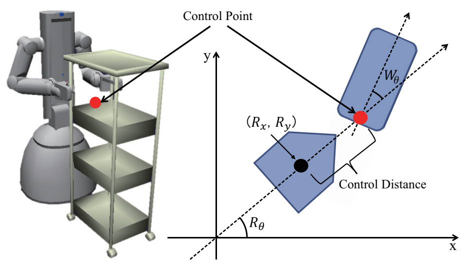

Fig. 7. Model of the robot pushing the wagon

4) If the wagon control point is not on the basic path (Fig. 8a), posture (R_θ) of the robot is changed so that the wagon control point passes along the basic path.
5) If the head of the wagon is not on the basic path (Fig. 8b), the relative posture (W_θ) of the wagon is modified so that it passes along the basic path.
6) Steps 3 through 5 are repeated until the end point is reached.

Figure 9 shows the results of wagon path planning, using example start and end points. These start (R_x, R_y, R_θ)=(2,380 mm, 1,000 mm, 0°) and end points (R_x, R_y, R_θ)=(450 mm, 2,300 mm, -6°) use the outcomes of wagon grip position planning and position planning for object delivery. This confirms that the movement traces of the wagon (indicated by green rectangles) are within the movement traces of the robot (indicated by the rounded gray shapes). Using this procedure we can simplify the space search without sacrificing the safety of the basic path diagram.

E. Integration of planning

We perform operation planning for overall item-carrying action, which integrates position, path and arm motion planning. First, we perform wagon grip position planning with the robot in order to grasp a wagon loaded with objects. Next, we perform position planning for object delivery in order to hand-deliver object to the target person. The results of these work position planning tasks becomes the candidate movement target positions for the path planning of the robot and the wagon. Finally, we perform an action planning that combines the above-mentioned planning tasks, from the initial position of the robot to the path the robot takes until grasping the wagon, and the path the wagon takes until the robot reaches the position at which the robot can deliver the object. For example, if there are four candidate positions for wagon gripping and four candidate positions for object delivery around the target person, then we can plan 16 different actions, as shown in Fig. 10. The various action sequences obtained from this procedure are then evaluated to choose the optimum sequence.

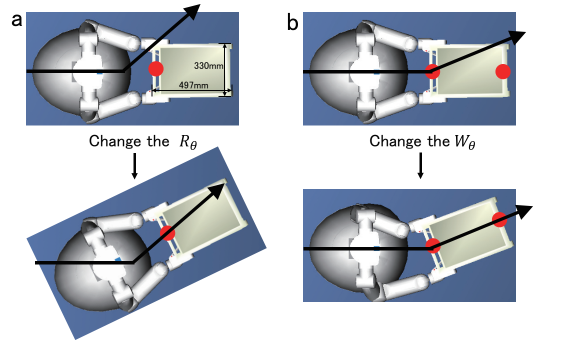

Fig. 8. Wagon path planning: (a) robot posture plan, (b) wagon posture plan.

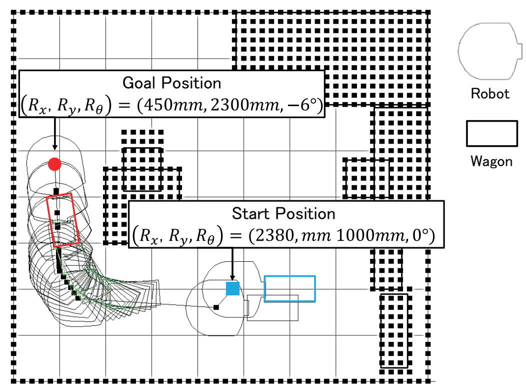

Fig. 9. Wagon movement path

F. Evaluation of efficiency and safety

We evaluate each candidate action sequence based on efficiency and safety, as shown in Eq. (7).

$$E_{value} = \alpha \frac{Len_{min}}{Length} + \beta \frac{Rot_{min}}{Rotation} + \gamma ViewRatio \quad (7)$$

The α, β, γ are respectively the weight values of $Length$, $Rotation$ and $ViewRatio$. The $Length$ and $Rotation$ represent the total distance traveled and total rotation angle. The Len_{min} and Rot_{min} represent the minimum values of all the candidate action. First and second terms of Eq. (7) are the metrics for efficiency of action. $ViewRatio$ is *The number of motion planning points in the person's visual field* out of *Total number of motion planning point*. It means the percentage for the number of motion planning points that exist in the a visual field of person.

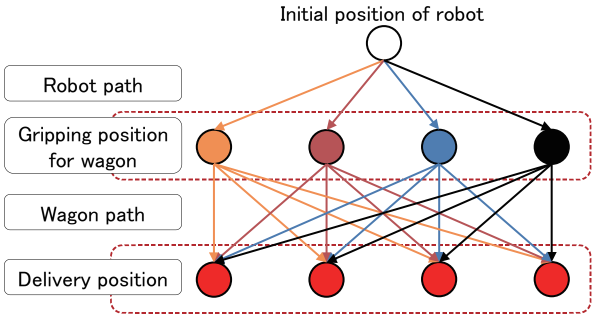

Fig. 10. Motion planning candidate

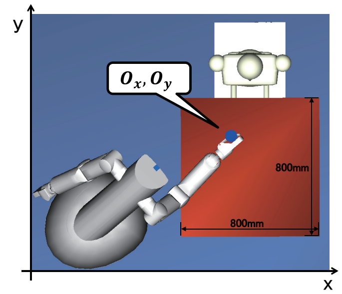

Fig. 12. Condition under which the object delivery experiment was conducted

Fig. 11. Object gripping experiment: (a) initial state, (b) intermediate position, (c) object delivery attitude.

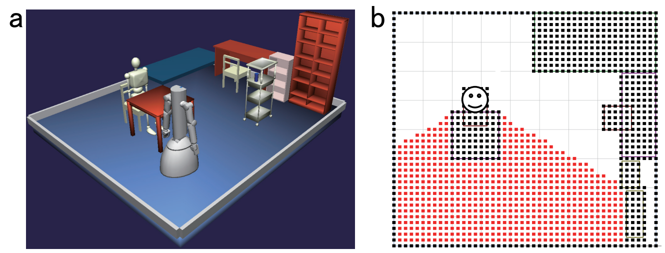

Fig. 13. Simulation conditions: (a) initial state of human, robot and wagon, (b) visual field of person

IV. Experiments

In this section, we present the results of fundamental experiments described below using an actual robot.

1) Experiment to examine gripping and delivery of object
2) Simulation of motion planning
3) Service experiments

A. Experiment to examine gripping and delivery of object

We performed an operation experiment in which a robot grasps an object located on a wagon and delivers the object to a person. As a prerequisite for this service, the object are assumed to have been placed on the wagon, and their positions are known in advance. After performing the experiment 10 times, the robot successfully grabbed and delivered the object in all cases. The operating state is shown in Fig. 11.

We measured the displacement of the position of object (O_x, O_y in Fig. 12) and the linear distance (d) between the measured value and the true value at the time of delivery, to verify the effect of rotation errors or arm posture errors. The results are listed in Table II.

The distance error of the position of the object at the time of delivery was 35.8 mm. According to the manipulability degree, it is possible to cope with these errors, because the system plans a delivery posture with some extra margin in which persons and robots can move their hands.

TABLE II
Results for object delivery position

	$O_x(mm)$	$O_y(mm)$	$d(mm)$
True value	1,290.0	2,100.0	0.0
Avg. of measured values	1,301.9	2,078.1	35.8
Avg. error	15.9	31.5	35.8
Maximum error	33.0	66.0	70.6
Minimal error	0.0	1.0	2.2

B. Simulation of motion planning

We set up one initial position for the robot (R_x, R_y, R_θ)=(1,000 mm, 1,000 mm, 0°), the wagon (W_x, W_y, W_θ)=(3,000 mm, 1,000 mm, 0°), and the target person (H_x, H_y, H_θ)=(1,400 mm, 2,500 mm, -90°) and assume the person is in a sitting state as shown in Fig. 13a. Moreover, the range of vision of this person is shown in Fig. 13b by the red area. For each motion planning, two positions are candidate wagon grip positions (Fig. 15b and 16b), and three positions are candidate object delivery positions (Fig. 15c, 15d, 15e and Fig. 16c, 16d, 16e), for a total of six possible action planning scenarios (section III-E).

The action planning result that passes over wagon grip candidate 1 is shown in Fig. 15, whereas the action planning result that passes over wagon grip candidate 2 is shown in Fig. 16. Furthermore, the evaluation values that changed the weight of each evaluation for each planning result are listed in Tables III through V. The α, β, γ of these Tables are respectively the weight values of $Length$, $Rotation$ and $ViewRatio$. in Eq. (7) (section III-F). The actions of Plan 2-3 were the most highly evaluated. Figures 16b and 16e indicate that all of the actions occur within the field of vision of the person. Since the target person can monitor the robot's actions at all times, the risk of the robot unexpectedly touching a person is lower, and if the robot misses an action, the situation can be dealt with immediately. The action plan chosen from the above results according to the proposed evaluation values exhibits both efficiency and high safety.

C. Service experiments

We performed a service experiment for the carriage of object, in accordance with the combined results of these

TABLE V

RESULTS OF EFFICIENCY EVALUATION ($\alpha = \beta = 1.0, \gamma = 0.0$)

Plan No.	1-1	1-2	1-3	**2-1**	2-2	2-3
Length (mm)	4298.2	7336.9	6650.9	**3443.5**	4737.6	4045.6
Estimated length	0.8	0.5	0.5	**1.0**	0.7	0.9
Rotation (°)	362.3	478.8	480.6	225.5	233.6	**212.6**
Estimated rotation	0.6	0.4	0.4	0.9	0.9	**1.0**
Estimated efficiency	1.4	0.9	1.0	**1.9**	1.6	1.9

TABLE III

EVALUATION RESULTS ($\alpha = \beta = \gamma = 1.0$)

Plan No.	1-1	1-2	1-3	2-1	2-2	**2-3**
Length	0.8	0.5	0.5	1.0	0.7	0.9
Rotation	0.6	0.4	0.4	0.9	0.9	1.0
View	0.5	0.3	0.8	0.8	0.9	1.0
Total Estimation	1.9	1.3	1.8	2.8	2.6	**2.9**

TABLE IV

RESULTS OF SAFETY EVALUATION ($\alpha = \beta = 0.0, \gamma = 1.0$)

Plan No.	1-1	1-2	1-3	2-1	2-2	**2-3**
View Evaluation	0.5	0.3	0.8	0.8	0.9	**1.0**

planning sequences. The state of the sequence of actions is shown in Fig. 14.

The initial conditions were the same for the simulation (Fig. 13), and were set up as shown in Fig. 14a. The procedure for service execution is as follows:

1) Path planning is executed from the initial position to the position at which the object is delivered.
2) The robot moves from its initial position to the position at which it grips the wagon.
3) The robot position is corrected according to its RGB-D camera.
4) The arm trajectory is planned and executed in order to grasp the wagon (Fig. 14b).
5) The robot moves to the delivery position while pushing the wagon (Fig. 14c).
6) The arm trajectory is planned and executed in order to separate the arm from the wagon.
7) The arm trajectory is planned and executed in order to grasp the target object from the top of the wagon (Fig. 14d).
8) The arm trajectory is planned and executed in order to hold the object in the position in which it is delivered (Fig. 14e and Fig. 14f).

This service was carried out successfully, avoiding any contact with the environment. The total time for the task execution is 312 sec in case the maximum velocity of SmartPal-V is limited to 10 mm/sec in terms of safety. Moreover, the robot position was confirmed to always be within the range of vision of the subject during execution. Accordingly, we can say that the planned actions had an appropriate level of safety. Moreover, there was a margin for the movement of hands, as shown in Fig. 14f, for which the delivery process could appropriately cope with the movement errors of the robot.

(a) Initial state (b) Wagon gripping (c) Wagon movement (d) Goods gripping (e) Goods delivery (f) Goods delivery (from another point of view)

Fig. 14. State of the service execution

V. CONCLUSIONS

In this work we presented a coordinate motion planning technique for a fetch-and-give task using a wagon and a service robot. When the robot hands over the object to the user, both the handover position of the object and the base position of the robot must be planned according to the user's posture. We proposed a handover motion which is planned by considering the manipulability of both a robot and a person. We also proposed a total motion planning technique for a fetch-and-give task with a wagon. It consists of sub-planning, integration, and evaluation of the planning to implement the fetch-and-give task. The actions that integrate overall planning are obtained from a combination of various individual planning threads. The integration method is considered to be not only efficient but also safe in places such as hospitals and elderly care houses. We carried out several experiments for a fetch-and-give task using a service robot in the informationally structured platform and verified the validity of the proposed technique. In the future, we intend to design and prepare a long-term experiment in which we can test the complete system for a longer period of time.

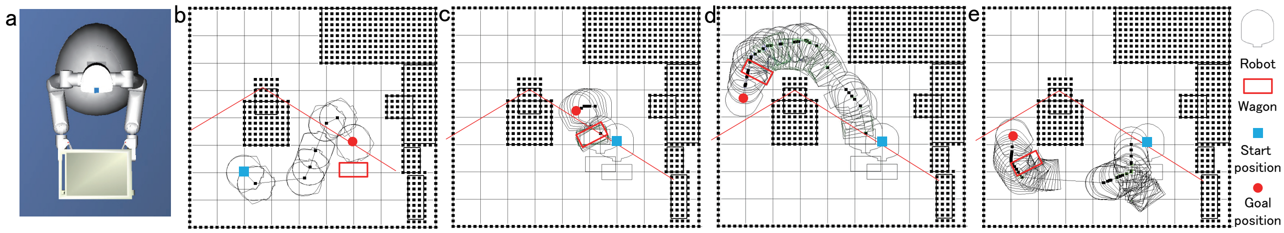

Fig. 15. Planning results for object delivery wagon route for holding candidate position using plan 1 : (a) holding candidate attitude, (b) robot path to wagon grip candidate 1, wagon route to object delivery position candidate 1,2,3 (c,d,e)

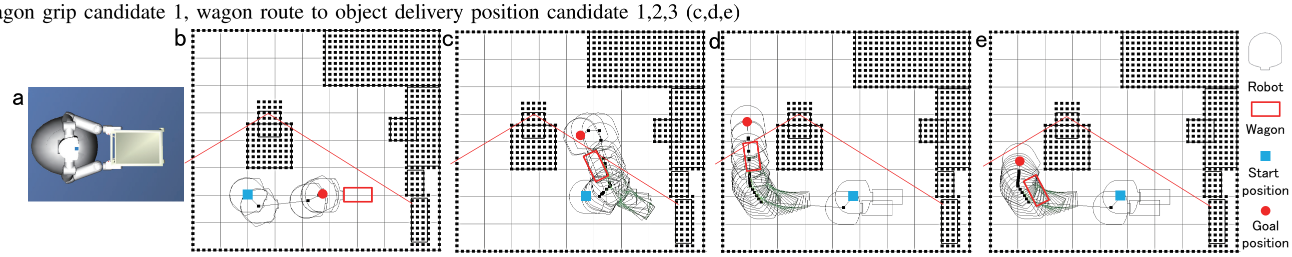

Fig. 16. Planning results for object delivery wagon route for holding candidate position using plan 2 : (a) holding candidate attitude, (b) robot path to wagon grip candidate 2, wagon route to object delivery position candidate 1,2,3 (c,d,e)

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