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Abstract

For home-service robots one of the most common interactions with humans is the handing over of objects using arms and hands of anthropomorphic robots. We propose advanced methods of determination of grasp sites for handover operations that incorporate especially etiquettes which factors include object shapes, object functions, and safety. We also address different operations for handover: one-handed handover with one grasp, two-step handover with midair re-grasp, and two-handed handover. We show the effectiveness of our algorithm for interaction between humans and robots with graphical simulations.

Keywords: humanoid home-service robot, grasp planning, motion planning, etiquette, handover operation, dual arms and hands

1 Introduction

For the last ten years, home-service robots have been expected to provide various kinds of services to humans in human-robot coexisting environments. This puts demands on the service robots to have more intelligence with multi-functional capabilities, which in turn requires research on dexterous arms and hands. The handover motion involves holding of an object by both a human and a robot, and implicates functional and social relationship between the giver and the receiver. It needs to consider many grasp constraints including object shapes, collision between the robot hand and all other objects, object functionalities, safety with manners mainly. Etiquette for the human-robot interaction is especially important for robots engaged in household service and in public places to interact with humans in a friendly manner. If service robots could perform with respectable manner while interacting with people, people shown those acts would feel respected and well served with convenience, regardless whether the performer is human or not. Although there is no unique way to define the etiquette sensitive behaviours of robots, the etiquettes deal with polite ways of handing over objects as defined by customs of cultures, usually to facilitate the receiver’s convenience after the object handover. When handing a book over, for example, it is considerate of the giver to grasp it so the book is right side up in the receiver’s viewpoint. The receiver then can open the book without re-orientation. A pair of scissors is usually handed over so that the receiver can directly insert fingers in the handles. Tools such as a hammer or a screw driver should be grasped with their usage in mind. When handing over an object with a sharp edge, robots and humans should avoid grasping dangerous sites for safety.

Figure 1: A humanoid home-service robot IDRO (a) handover operation (b) grasp that does not consider grasp sites for receiver and (c) grasp that does.

In addition to determining grasp sites with the above grasp constraints (call them GC5), we address three different modes of handover operations: one-handed handover with one grasp (H1G1), two-step handover with a midair re-grasp to transfer the object from one
hand to the other (H2G2), and two-handed handover (H2G1). The factors determining the mode of handover include object size, weight, the initial pose, and its spatial relationship with nearby objects. Three separate but related grasp planners are developed to support the corresponding modes of handover operations, which are tested with a home-service robot called IDRO shown in Fig. 1. Simply constraints related to etiquettes is well illustrated in Fig. 1, which shows a robot handing over a remote control with a grasp that does not consider a place for human to grasp (Fig. 1(b)), and that considers the human grasp (Fig. 1(c)).

2 Previous Work
Over the past two decades, many grasping algorithms have been developed for various grippers and multi-fingered humanoids’ hands. Cutkosky and Wright have classified the types of grips needed in a manufacturing environment and examined how the task and object geometry affect the choice of grasp [2]. Stansfield has chosen a simple classification and built a rule-based system that provides a set of possible hand pre-shapes and reach directions for pre-contact stage of grasping [13]. This algorithm doesn’t evaluate all possible grasps. Borst et al. apply grasp planning to task wrench space [1].

For object manipulation several papers present grasp algorithms [3, 10], which are mostly concerned with finding a fixed number of contact locations. Other systems developed for particular hands usually restrict the problem, e.g., allowing one contact per finger [5]. Hasegawa et al. [4] propose a one-handed re-grasping strategy for positioning and orienting an object, but it doesn’t consider using two hands. Hwang et al. and Kaneko et al. present grasping and motion planning algorithms for humanoid robots [8, 9]. Hirata et al. have developed coordinated control algorithms to handle a single object with multiple manipulators [6]. Most of the grasping algorithms focus on form/form closure and object manipulability, and do not consider etiquettes, object functions, and safety. They are suitable for manipulating objects and fixing mechanical parts in manufacturing environments. In contrast, our paper presents grasp planning algorithms specifically designed for handover operations between humans and robots. To our knowledge, our paper is the first to address etiquettes and safety issues for grasp planning.

3 Grasp Planners for Handover Operations
In this paper, we develop grasp planners for a parallel jaw gripper. Although it is not as versatile as a multi-fingered hand, it helps us to concentrate on handover grasps satisfying GC5. Objects are modelled as polyhedron, and the information about etiquette factors which also include object functions, and safety represented by tagging handles of tool objects, dangerous features with appropriate flags. We first define the terminology for grasping. A grasp site can be defined with a coordinate frame with position \( x, y, z \), and orientation vectors \( n, o, a \), defining the \( x, y, z \) axes of the coordinate frame. The gripper has a fixed, associated coordinate frame called \( F_{grasp} \), located between the finger tips with z-axis parallel to the finger length (Fig. 2(a)). A robot hand approaches the object to be grasped along vector \( a \). The gripper opens/closes by moving its fingers along vector \( o \), and \( n \) forms a right-hand coordinate system with \( o \) and \( a \).

Given a grasp site of an object \( F_{gsite} \), the grasping operation is accomplished by first moving the robot hand so as to match \( F_{grasp} \) to \( F_{gsite} \), and then closing its fingers until they contact the object surface (Fig. 2(b)). Grasp and re-grasp also display with a knife (Fig. 2(d), (e)).

![Figure 2: Two-fingered robot gripper (a) \( F_{grasp} \) attached to robot hand. (b) before matching \( F_{grasp} \) to \( F_{gsite} \). (c) after. (d) grasp handle area of a knife by first gripper (e) re-grasp cutting edge of a knife by second gripper to handover a knife to human](image)

We simply provide with our arm motion planning for handover operations even if our paper is focused on grasp planning. For the motion planning of handover objects to human the algorithm divides the trajectory up to six segments (1.move, 2.approach, 3.decid_ of__grasp_site, 4.grab, 5.lift, 6. handover an object to human), each of which can be independently generated using interpolation for position and orientation. The robot moves to the space above the object to be grasped by a given distance. The orientation changes linearly from the initial to the object grasping orientation with the gripper open. The robot arms then moves down to the object. The gripper then moves to the chosen grasp site that avoids dangerous features and respects manners, functionality, safety. And then, the gripper continuously closes to grab the object. The robot then lifts up the object, goes to the human, and handover the object. In order to prevent unreachable grasps sites of the object from being planned, the user may import a world model containing obstacles as well as the robot arm model so that reachable constraints may be considered. Traditionally, for the arm motion planner inverse kinematics solvers can be divided into two categories: analytic and numerical solvers. Most industrial manipulators are designed to have analytic
solutions for efficient and robust control. Paden [11] independently discussed methods to solve an inverse kinematics problem by reducing it into a series of simpler sub-problems whose closed-form solutions are known. We are using numerical method using Jacobian matrix and its pseudo inverse which relies on an interactive process to obtain solution. Zhao and Badler [14] formulated the inverse kinematics problem of a human figure as a constrained non-linear optimization problem. Rose et al. [12] extended this formulation to handle variational constraints that hold over an interval of motion frames. Our Arm has 6 DOFs of joint angles and its end-effector manipulated to reach at target position well (Fig. 6).

3.1 H1G1 - Grasp Planning for One-Handed Handover

The following algorithm works for a convex polyhedral object. For every pair of faces of a polyhedron, check whether they are nearly parallel. If they are not, go to the next pair. If they are, check whether the distance between the faces is less than the gripper’s maximum width. If not, go to the next pair of faces. If it is, project the vertices of the two faces along the common normal to generate two polygons, and see if the polygons’ intersection has an enough area. If it does, the approximate centre of the intersection, Pic, is the origin of a possible grasp site (Fig. 3(a)). The orientation of the grasp site is determined by matching x, y, z and o of the grasp site with those of Fgrasp, and then rotating the robot hand about o axis at a finite interval, storing the angles without collisions between the hand and other objects (Fig. 6(g)). Repeat this for all pairs of faces to get all possible grasp sites of the object.

For purpose of handover an object to people robot should consider receiver’s grasp site, C, before determination of his grasp site. We assume human grasp the same surface of an objet with robot grasping sites. To be considering receiver’s safety and conveniences for etiquettes we address new grasp method for handover operation. Fig. 3(b) shows us that determination of grasp sites for handover operation with considering human’s grasp sites: From the origin of a grasp site, Pic, robot get new grasp site, A, which is determine half of distance from closed direction at robot to Pic, and human get C grasp site which is decided \((A+B)/2 = C\), B is measured closed sites from human. By the method, human receive a remote controller handily.

3.2 H2G2 - Grasp Planning for Re-grasp Handover using Dual Hands

If there is no Fgsite that satisfies GC5, a two-step handover with a re-grasp is considered. Let’s assume we pick up the object with the first hand, transfer it to the second, and handover to the human with the second. We first place a copy of the object to be grasped in midair. We then find all grasp sites, Ffirst, that can be used to move the object in midair back to the initial object position – enforcing satisfaction of GC5 except the functionality and etiquette constraints. Next, we find all grasp sites, Fsecond, that can be used to handover the object from the midair position to a human – enforcing satisfaction of all of GC5 plus the collision avoidance between the first and the second hand. The grasp sites that belong to both Ffirst and Fsecond are the ones that can be used for a two-step handover with a midair re-grasp.

3.3 H2G1 - Grasp Planning for Two-Handed Handover

When a robot passes a large or heavy object over to a human, a two-handed handover operation is necessary for stability and safety. For this situation, we need to consider 4 hands – 2 robot hands and 2 human hands. In some countries, it is in the right manner to give an object with two hands when the receiver is an older person or in a superior position. For this situation, we need to consider three hands – two robot hands and one human hand. In either case, the robot needs to hold the object at the far-left and far-right sides of the object and present it to a human receiver. The human

Figure 3: Grasp sites (a) intersection of the projections of parallel faces of a slanted octagonal prism (b) determination of grasp sites with considering human grasp sites

Figure 4: Handover with a midair re-grasping

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then uses either two hands (large-object case) or one hand (etiquette case) to accept the object. Our algorithm therefore predicts the grasp sites of the human hand, attaches the geometric model of the human hand at one or two grasp sites, and regards them as obstacles in planning the grasp sites for the robot hands – one on the right side and the other on the left side (Fig. 5).

**Figure 5:** Grasp planning for two robot hands assuming a one-handed grasp for the human receiver

Finally, a two-handed grasp site is shown in Fig. 7(h). For arm motion we have experimented motion planning with virtual robot in our simulator which is designed based on real robot IDRO arm (Fig. 6). The experiment is focused on dual-arm motion planning for handover operation between robot and human. For the first arm and hand end-effector position robot is manipulated from base coordinate to grab an object by inverse kinematics. And it is moved to reachable area for handover to human or for transferring to the other hand in midair. In order to transfer an object to the other hand, final reached position of first hand with grabbed an object can be set as end-effector position of the other hand. And then, we apply re-inverse kinematics to manipulate second arm. (Fig. 8). Finally, robot hand over an object to human after transfer an object. All of the motion planning for handover operation also applied our handover grasp planner algorithms to determine optimal grasp site for human.

**5 Conclusions and Future Work**

This paper presents grasp determination algorithms for three different object-handover operations in esteem etiquette factors: one-handed object-handover with a single grasp, two-handed handover with a midair re-grasp, and two-handed handover. Our grasping algorithms respect the constraints associated with etiquettes which include object shapes, object functions and safety. We are specifically developed a home-service robot with two arms, and to our knowledge are the first grasp planners to consider social constraints, i.e., etiquettes, in addition to the geometric constraints. The etiquette sensitive grasp planner has been tested with our robot IDRO in household environment, and has shown a satisfactory performance. We believe our planner would make humans feel comfortable and respected, which is one of the most important factors in determining the success of human-robot interaction.

Many issues encountered during our work need to be addressed in future research. First of all, we need to extend our algorithms to multi-fingered hands since home-service robots need such hands to use a hammer or a knife. To be effective in real home environments, the information related to grasping needs be stored in a systematic knowledge base to scale up to hundreds of objects. Inclusion of object-strength information is useful for control of grasping force during interaction and manipulation. Also, force control for grasp planning is one of the important issues to manage deformable objects as much as rigid object. We will implement new grasp algorithms to handle a deformable object using flexible fingertips. Another promising path of further research is the grasp planning for different tasks other than object handover such as handshaking.
Figure 7: Grasp planning for household objects: (a) a sphere type object (b) grasp sites with x(red), y(black), z(blue) axis frames around a sphere (c)(d)(e)(f) grasping in midair (g) feasible grasp sites of a book with collision detection (h) two-handed grasp sites
6 References


