# Grasp Planning
# for Anthropomorphic Home-Service Robot

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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 object shapes, object functions, safety and etiquettes. We also address different operations for handover: one-handed handover with one grasp, two-step handover with midair regrasp, and two-handed handover. We show the effectiveness of our algorithm for interaction between humans and robots with graphical simulations.

**Key words**: Grasp Planning, Home-Service Robot

## 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 and manners. 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 screwdriver 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.

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 regrasp 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. 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.

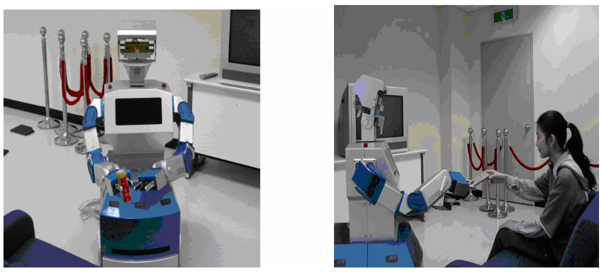


Fig. 1. A humanoid home-service robot IDRO

## 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 preshapes and reach directions for pre-contact stage of grasping [11]. 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 regrasping 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/force closure and object manipulability, and do not consider object functions, safety and etiquettes. They are suitable for manipulating objects and designing fixtures 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 modeled as polyhedra, and the information about object functions, safety, and etiquettes are 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 associated with it a fixed coordinate frame called *Fgrasp*, located between the finger tips with z-axis parallel to the finger length (Fig. 2a). 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 *Fgsite*, the grasping operation is accomplished by first moving the robot hand so as to match *Fgrasp* to *Fgsite*, and then closing its fingers until they contact the object surface (Fig. 2b).

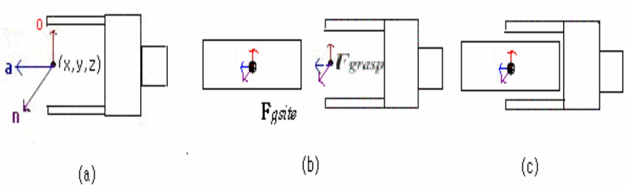



Fig. 2. Two-fingered robot gripper (a) *Fgrasp* attached to robot hand. (b) before matching *Fgrasp* to *Fgsite*. (c) after.

### 3.1 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 center of the intersection, *Pic*, is the origin of a possible grasp site (Fig. 3). 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. 6d). 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. To be considering receiver's safety and convenience we address new grasp method for handover operation. Fig. 8(b) shows us that determination of grasp sites for handover operation: 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.

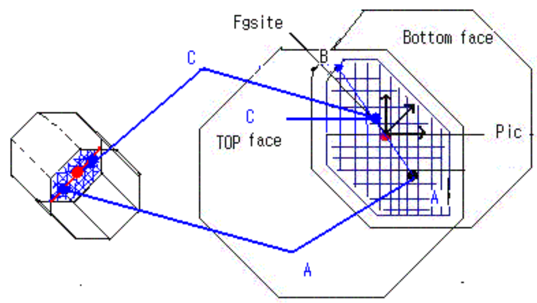



Fig. 3. Intersection of the projections of parallel faces of a slanted octagonal prism

### 3.2 Grasp Planning for Handover with Regrasp

If there is no *Fgsite* that satisfies GC5, a two-step handover with a regrasp is considered. Let's assume we pick up the object with the first hand, transfer it to the second, and handover to a 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 regrasp.

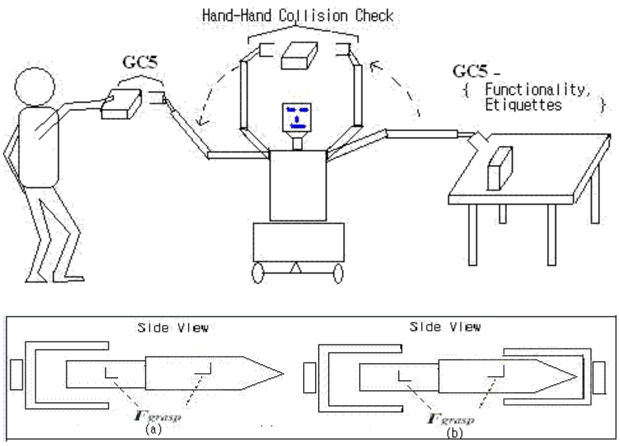



Fig. 4. Handover with a midair re-grasping: (a)gripper for *Ffirst* (b)gripper for *Fsecond*

### 3.3 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 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 (see Fig. 5).

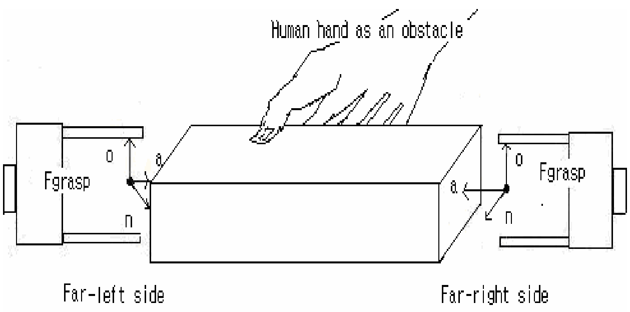
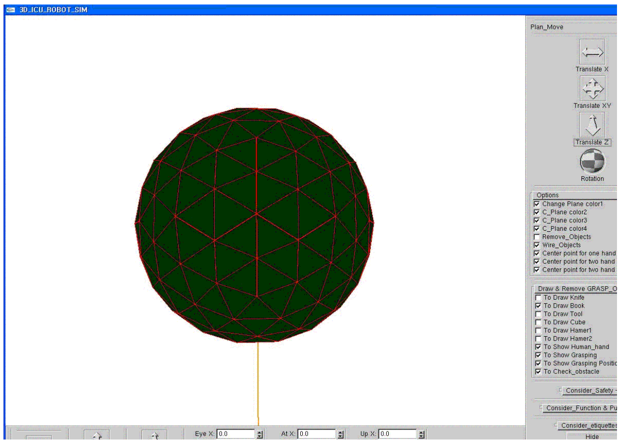


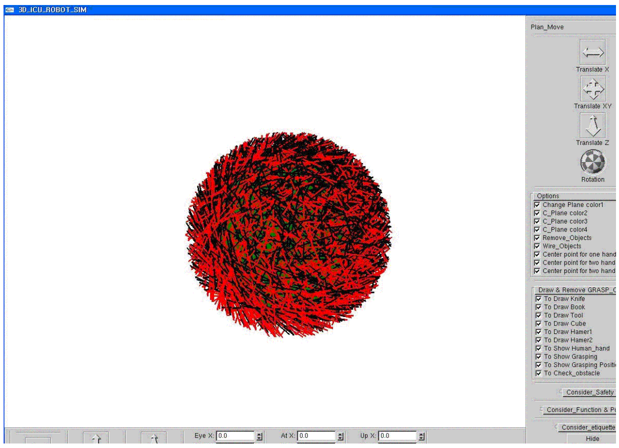

Fig. 5. Grasp planning for two robot hands assuming a one-handed grasp for the human receiver.

## 4. Experiments

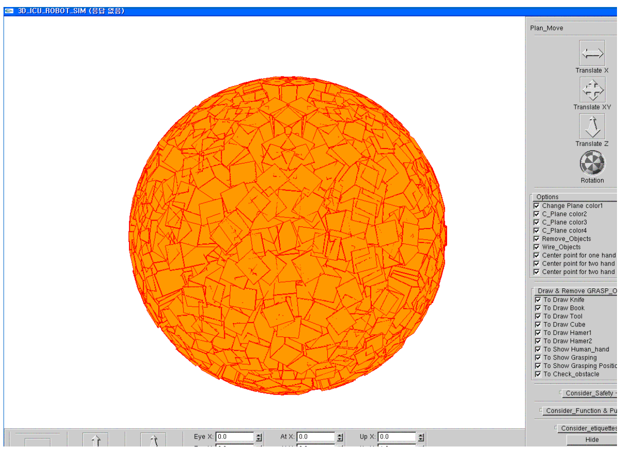
We have implemented our algorithm in a graphical simulation and tested with several common household objects including a ball, a book, a knife and a hammer. Fig. 6, 7(a) shows the result of all the possible grasp sites of an object in midair. Fig. 7(b) and 7(c) show two different sets of grasp sites for a hammer: one as a nail driver and the other as a nail extractor. Fig. 7(d) shows grasp sites for a book on the table that avoids collision between robot hand and objects in the environment. Finally, a two-handed grasp site is shown in Fig. 7(e).



(a) Convex polyhedral sphere

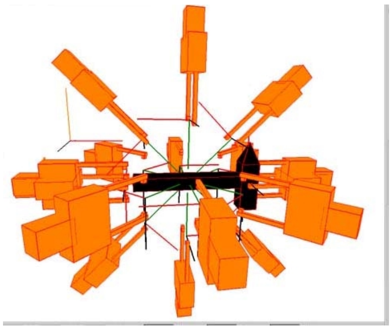


(b) Grasp sites with x (red), y (black), z (blue) axis frames around a sphere

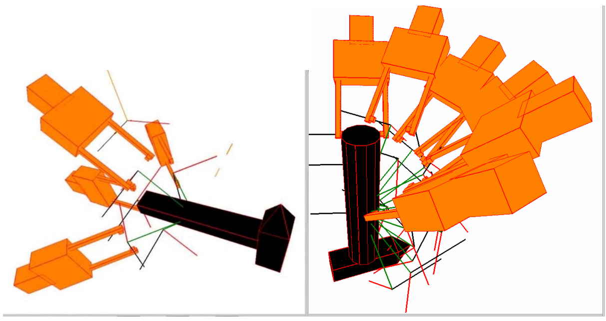


(c) All of the possible grasping sites: lots of yellow grippers set around a sphere

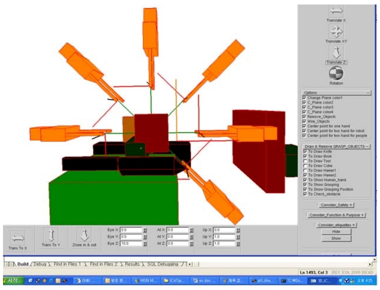
Fig. 6. Grasp planning of sphere object



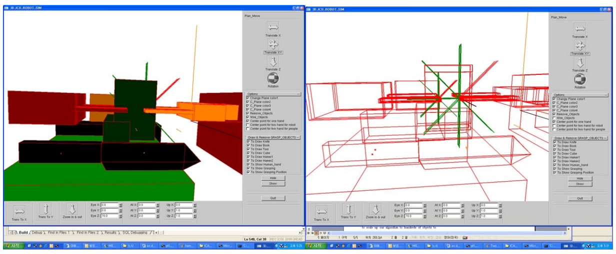
(a) Grasping in midair



(b) Driving a nail in. (c) Pulling out a nail



(d) Feasible grasp sites of a book with collision detection



(e) Two-handed grasp sites

Fig. 7. Grasp planning of several household objects

## 5. Conclusions and Future Work

This paper presents grasp determination algorithms for three different object-handover operations: one-handed object handover with a single grasp, two-handed handover with a midair regrasp, and two-handed handover. Our grasping algorithms respect the constraints associated with object shapes, object functions, safety and etiquettes. Our algorithms 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. 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 systematically in a 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. Another promising path of further research is the grasp planning for different tasks other than object handover such as handshaking, turning a doorknob, opening a bottle cup, etc.

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