IN-63

198113

13 P

NASA Technical Memorandum 104785

Model-Based Automatic Generation of Grasping Regions

David A. Bloss

November 1993

(NASA-TM-104785) MODEL-BASED AUTOMATIC GENERATION OF GRASPING REGIONS (NASA) 13 p

N94-21550

Unclas

G3/63 0198113

NASA Technical Memorandum 104785

Model-Based Automatic Generation of Grasping Regions

David A. Bloss

Lyndon B. Johnson Space Center

Houston, Texas

November 1993

CONTENTS

FIGURES

INTRODUCTION

Recently, there has been considerable interest in the development of multifingered robotic end effectors which could provide robots with greater dexterity than is possible with traditional, fixed structure devices [11]. One of the most fundamental questions arising from the study of such multifingered robotic end effectors is the determination of an appropriate grasp [5]. One very important notion in grasp selection is that of form closure. In the remainder of this paper, form closure will be defined as follows:

> ***Definition***: *Form Closure*: A fixed set of contacts on a rigid body is said to exhibit form closure if the body's equilibrium is maintained despite the application of any possible externally applied wrench (force and moment). Equivalently, the contacts prevent all motions of the body, including infinitesimal motions [12].

With this definition, a method has been developed to determine not only if a specific grasp is in form closure, but to what extent that grasp represents a form closure grasp. This allows for the comparison of several specific grasps of the same object.

In order to effectively represent the graspable points of an object, it is important to exploit the symmetries of any specific, valid grasp on that object. With this information it is possible to construct graspable regions on an object, where any grasp within that specified region will be in form closure. This allows for continuous grasping regions as opposed to many specific grasp points on an object, thereby reducing the complexity of grasp-related tasks such as tracking.

A method has been developed, given a model of the target object and of the grasping end effector, to automatically generate form closure grasp transformations from the end effector to the target object, and to associate appropriate translational and rotational symmetries with the transformation if they exist.

MODEL-BASED APPROACH

This algorithm assumes that the geometry of both the target object and the robotic end effector is known a priori in the form of a CAD model. This allows easy integration into many systems grasping diverse objects with virtually any type of end effector.

The target object models are first divided into their convex components, and these components are further divided into planer polygons. Each polygon's center and outward-facing unit normal vector is then calculated. The end effectors model is given a coordinate system with its origin at the center of the palm, Z axis aligned with the outward-facing unit normal of the palm, and Y axis pointing toward the thumb of the end effector. Once these operations have been performed on the object and end effector models, it is possible to generate initial form closure grasp transformations which will be the basis of the final grasp regions defined for the target object.

INITIAL GRASP TRANSFORMATION

The initial step in generating specific, valid grasp transformations is to place the model of the end effector at each polygon's center point, with orientation of the palm (the end effector's Z axis) opposite that of the polygon's outward facing unit normal. This proves to be a very simple starting point that, with the addition of translational and rotational symmetries, is easily expanded into regions that span nearly all of the graspable points on the object.

An initial collision check is then performed between the end effector model and the target object model. If initial collisions are found, the end effector model is moved in its negative Z direction until no collisions exist.

The next step is to close the end effector model, until the fingers collide with other parts of the end effector or the target object, and check for form closure.

All the contacts between the target object and the end effector are modeled as "soft-finger" contacts. That is, the friction over the area of contact allows the finger to exert pure torques in addition to pure forces pointing into the friction cone. The finger can exert torques in both directions, about the normal axis of the point of contact. So the wrench convex is described by a one-sided friction cone plus a two-sided torque [8]. This assumption is made because of the types of materials coming into contact in the particular implementation of the algorithm, and is not an issue of the algorithm itself.

With this assumption, a grasp with two soft-finger contacts is form closure if and only if the segment P1P2, or P2P1, joining the two points of contact P1 and P2, points strictly into and out of the friction cones respectively at P1, P2 (figure 1) [8]. Simply enough, if a grasp has two contacts which could satisfy this condition, it is considered a form closure grasp.

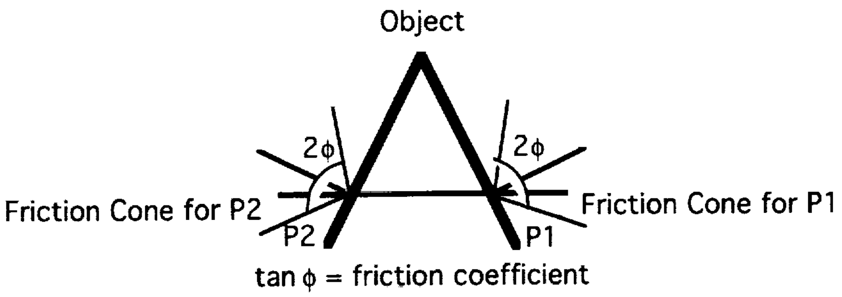


Figure 1: Form Closure with two soft-finger contacts

Next, the grasp is given a relative strength rating according to the following equation:

$$\sum_{i=0}^{\#\text{ contact pairs}} 1 + \frac{K}{\text{min\_dist (P1P2, Center of Target)}}$$

Once this initial rating is obtained, the end effector is rotated about its Z axis to find the particular orientation that produces the greatest strength rating. If no orientation can produce a grasp rating above zero (representing a grasp not in form closure), then that polygon's center point is disregarded as a grasp point, and the next potential point is investigated. Otherwise, the translational and rotational symmetries of the transformation (position and orientation) with the greatest relative strength rating are investigated, and a grasping region is formed.

SYMMETRIES OF THE INITIAL GRASP

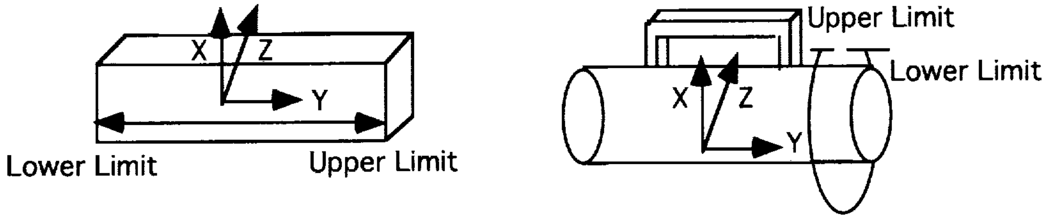
There are four types of symmetries that are searched for in this algorithm, each demanding that the initial rating of each valid grasp be conserved. They are limited translational, limited rotational, unlimited rotational, and discrete rotational (figure 2).

Limited translational symmetry is recognized when an initial transformation can be translated in a direction within specified limits (figure 2a). It is tested for by simply sliding the initial transformation along its Y axis until a valid grasp rating is no longer obtained, or a collision occurs between the end effector and the target object. This leads to definition by a directional vector of translation, and the relative limits of translation.

Limited rotational symmetry occurs when an initial transformation can be rotated about a point in a direction within specified limits (figure 2b). This is tested by rotating the initial transformation about the center point of the convex component it is near in its X and Y directions. If a valid grasp rating is maintained and a collision occurs at some point in the rotation, limited rotational symmetry is recognized and defined by a rotation point, a perpendicular rotation vector, and the relative limits of the rotation.

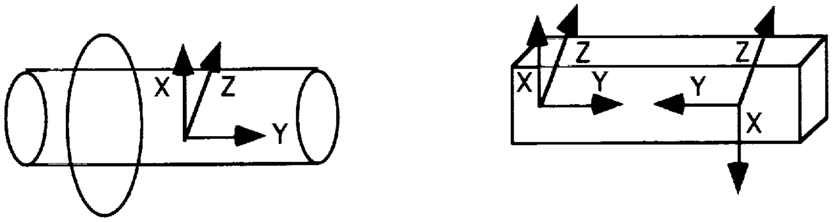
Unlimited rotational symmetry occurs when an initial transformation can be completely rotated about a point in a given direction (figure 2c). This is tested for in the same way as limited rotational symmetry, with the obvious exception of a collision in some portion of the rotation. A rotation point and a perpendicular rotation vector are all that is needed to define this symmetry.

Finally, discrete rotational symmetry is the case where the initial transformation can be rotated π radians about its Z axis (figure 2d). The test for this symmetry is to rotate the initial transformation π radians about its Z axis and test for a valid grasp rating. This leads to definition by a rotation axis (in the objects frame).



a: Limited Translational Symmetry

b: Limited Rotational Symmetry



c: Unlimited Rotational Symmetry

d: Discrete Rotational Symmetry

Figure 2: The four types of grasp symmetries

COMBINATION OF SYMMETRIES

The strength of this algorithm comes in the effective combination of the appropriate symmetries associated with the initial valid transformations. It is very important that, if a transformation is assigned two symmetries, these two symmetries create a continuous grasp region. Otherwise the symmetries must be separated, and two separate grasp regions formed. See figure 3 for a flow chart on how these continuous grasp regions are formed.

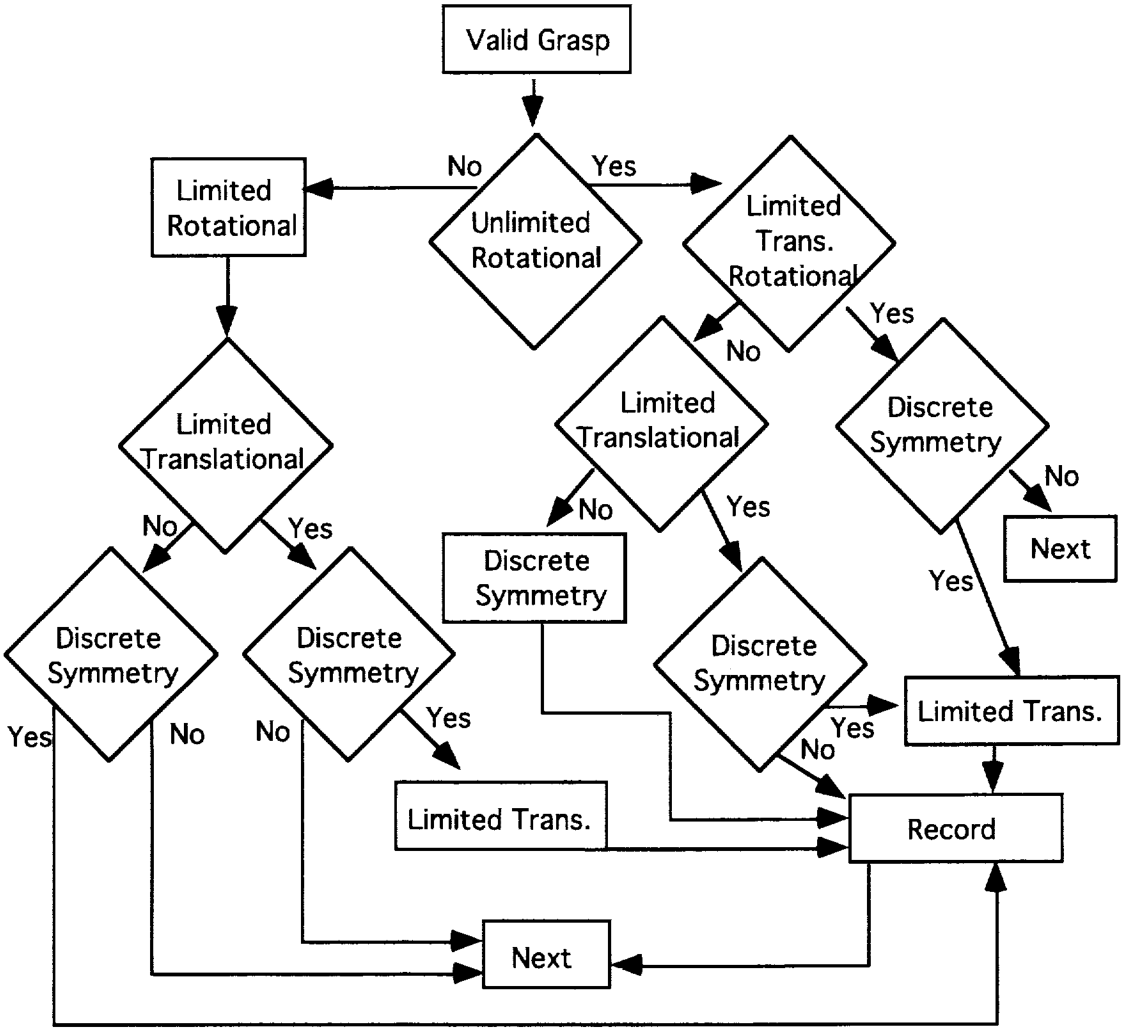


Figure 3: Formation of continuous grasp regions

CONCLUSIONS

The contributions of this algorithm are three-fold. First, it automates the process of grasp point selection. This was traditionally a tedious task performed either by trial and error, or by hand in a simulation.

Second, it defines a relative grasp rating to compare the strength of one grasp vs. another grasp of the same object. Although this is a very simple rating where "more is better," it can be easily altered to take into consideration task-based factors, thereby allowing a task-based planner to automatically select a grasping region.

Finally, it defines and effectively utilizes a set of grasping symmetries to produce continuous grasp regions as opposed to discrete grasp points. This allows for more freedom in a grasping system/subsystem in that a full region can be targeted as valid instead of trying to grasp exactly at a specified point on a target object.

This algorithm has been applied to the EVA Helper/Retriever project at the Johnson Space Center. The end effector currently in use is the Version 4 Jameson Hand, and the target objects include tools such as wrenches and ratchets, and space-specific targets such as star trackers and EMU batteries.

REFERENCES

[1] G. Anderson, "Grasping Software," EVA Retriever Project, NASA/Johnson Space Center, Houston, TX, December 1992.

[2] C. Z. Chammas and J. K. Salisbury, "HANDS: An Automatic Grasping Approach," MIT Artificial Intelligence Laboratory, Cambridge, MA.

[3] G. B. Dunn and J. Segen, "Automatic Discovery of Grasping Configurations," IEEE Transactions on Robotics and Automation, January 1988, pp. 396-401.

[4] K. A. Grimm and J. D. Erickson, etc., "An experiment in vision based autonomous grasping within a reduced gravity environment," SPIE Proc. 1829, Cooperative Intelligent Robotics in Space III, November 1992.

[5] Z. Li and S. Sastry, "Task Oriented Optimal Grasping by Multifingered Robotic Hands," IEEE Transactions on Robotics and Automation, March 1987, pp. 389-394.

[6] X. Markenscoff, L. Ni, and C. H. Papadimitriou, "The Geometry of Grasping," Int. J. Robotics Res., vol. 9, no. 4, pp. 61-74.

[7] D. J. Montana, "Contact Stability for Two-Fingered Grasps," IEEE Transactions on Robotics and Automation, vol. 8, no. 4, pp. 421-430.

[8] V. Nguyen, "Constructing Force-Closure Grasps in 3-D," submitted to Proc. IEEE Int. Conference on Robotics and Automation, Raleigh, March 1987.

[9] V. Nguyen, "Constructing Stable Grasps in 3-D," submitted to Proc. IEEE Int. Conference on Robotics and Automation, Raleigh, March 1987.

[10] S. A. Stansfield, "Robotic Grasping of Unknown Objects: A Knowledge-Based Approach," Sandia National Laboratories, Albuquerque, NM, June 1989.

[11] R. Tomovic, G. A. Bekey, and W. J. Karplus, "A Strategy for Grasp Synthesis with Multifingered Robot Hands," submitted to Proc. IEEE Int. Conference on Robotics and Automation, Raleigh, March 1987.

[12] J. C. Trinkle, "On the Stability and Instantaneous Velocity of Grasped Frictionless Objects," IEEE Transactions on Robotics and Automation, vol. 8, no. 5, pp. 560-572.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE
12/01/93

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Model-Based Automatic Generation of Grasping Regions

5. FUNDING NUMBERS

6. AUTHOR(S)
David A. Bloss

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Johnson Space Center
Houston, Texas 77058

8. PERFORMING ORGANIZATION REPORT NUMBERS
S-745

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D.C. 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
TM-104785

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified/unlimited
Available from :
National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, (703) 487-4600
Subject category: 63

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This paper discusses the problem of automatically generating stable grasp regions for a robotic end effector on a target object, given a model of the end effector and the object. In order to generate grasping regions, an initial valid grasp transformation from the end effector to the object is obtained based on form closure requirements, and appropriate rotational and translational symmetries are associated with that transformation in order to construct a valid, continuous grasping region. The main result of this algorithm is a list of specific, valid grasp transformations of the end effector to the target object, and the appropriate combinations of translational and rotational symmetries associated with each specific transformation in order to produce a continuous grasp region.

14. SUBJECT TERMS
symmetry, transformations, regions, models, robotics, translational motion

15. NUMBER OF PAGES
13

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT
Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std. 239-18
298-102