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Limited Mobility Grasps for Fixtureless Assembly

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Abstract

A novel approach to grasping with an end effector for the purposes of fixtureless assembly is presented. The grasping strategy is based on having the final position of the contacts determined by specific regions of the object geometry. The fingers are placed within limited spaces of the object and moved using frictionless contacts until motion ceases. The limited spaces usually take the form of concave edges or holes in the object. This strategy allows the positioning error to be determined by the accuracy of the part and is independent of the accuracy of the robotic manipulator. A new method for finding form closure is introduced based on maximizing the distances between contacts. The grasping strategy allows deterministic positioning of the object and also provides a means of convergence to these holding points. Testing was done in the plane with three fingers for several cases to show the sensitivity of the grasps to part geometry. The results show the position error is dependent on local shape and was reduced from 1 mm to 0.1 mm for several cases.

1 Introduction

Specially designed clamping devices known as fixtures are required for assembly of sheet metal parts in automotive and aircraft manufacturing. These fixtures are used to locate and immobilize the parts for spot welding and riveting. Since the number of sheet metal parts involved is large, between 300-500 per car for example, the number of fixtures required is substantial. When a new model is to be manufactured, new fixtures must be designed, built and installed in the plant. This retooling operation is very expensive. A recent potential solution to this problem is to use two robots to assemble and join the parts without fixtures. When parts are changed for a new model, only the robot's software should have to be changed. This approach is known as Robotic Fixtureless Assembly (RFA) [6]. RFA is expected to reduce the retooling costs by 80% [7].

The issue in RFA addressed in this paper is fixturing of the parts using a robotic end effector equipped with several movable fingers. The fixturing will be performed in 2-D. The contacts are modelled as frictionless point contacts (FPCs) since friction is not a reliable constraint for fixturing.

As in conventional fixturing the first goal is to locate the part accurately. Typically an accuracy of ± 0.1 mm is required [7]. Initial errors due to robot and part positioning must be overcome to achieve this goal. The second goal is immobilization (or form closure) of the part at its desired location. To achieve these goals the number and location of the contacts, and a suitable finger location strategy must be determined.

Asada [1] introduced an approach for accurately locating parts using reconfigurable fixtures. The contact points are selected such that the part's position relative to the fixture has a unique solution when all of the points are touching. Known as deterministic positioning, this approach is capable of significantly reducing the initial part placement errors. The final accuracy is a function of the accuracy of the part at the contact points, just as with conventional fixturing.

Many force closure models exist that determine the number and location of FPCs required to immobilize an object in 2-D [9] [8] [4] [3]. For FPCs in the plane, the locating strategy for force and form closure are equivalent. Nguyen [8] proved that a minimum of four FPCs are required for polygonal objects and developed a method to determine the ranges of allowable contact locations [8]. Faveron and Ponce extended Nguyen's work to include curved edges [3]. Rimon and Burdick [10], using a novel second order mobility theory, proved that only 3 FPC are required for generic 2-D objects.

These methods can be used to determine the number and locations for the contacts but disregard how and if the contact locations can be reached. In particular they do not account for the effects of initial robot and part positioning errors.

Corrective sensorless grasp planning has been dealt with by Brost [2] and Mason [5]. They provide a means for grasping despite initial positioning errors but do not guarantee the complete position of the object with respect to the robot, which is a