Automatic Tool Design for Robotic Caging Using Flexible Wires

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***Abstract*—In this work we present a method for automated tool design for robotic caging with flexible wires. We use computer vision to determine the end points of the flexible wire that will be used by a pair of robot arms to manipulate an object through a caging structure formed by the wire. We determine the configuration of the flexible wire (given its end points) through a geometric optimization scheme. We then deform the end point positions of the wire's configuration so that the wire can form a caging structure around the object. We discuss our work-in-progress and conclude with our plans for future work.**

I. Introduction

While there are many examples of prior work that examine the role that contact plays in robotic manipulation, few works have focused on robot tool formation, specifically automatically forming tools that leverage flexible contact with objects in the environment to accomplish tasks. Surveys on various techniques for robotic grasping have revealed robotic caging (constraining an object without force closure) to be an effective method for in-hand manipulation and object transport—the act of enclosing an object relaxes the amount of contacts and forces that need to be tracked during manipulation and the enclosure bounds the position tracking error that can occur [2]. External caging configurations, from which the object cannot escape given any perturbation, form pre-grasp cages and can be converted to grasping configurations by squeezing the cage points towards the object [4]. In this work we present a system pipeline to automatically design wire tool configurations for manipulating various objects through robotic caging.

To design the tool configuration (in our case, the shape of an elastic rod that a pair of robot manipulators will grasp), we build off of work performed in [1] that planned elastic rod configurations for sets of robot manipulators maneuvering rods through obstacles. Using this work, we have designed a geometric optimization scheme that can determine the configuration of an elastic rod (with knowledge of the rod's physical properties—bending stiffness, torsional stiffness, and whether the rod is Kirchhoff elastic) based upon the end points of the rod. Our system pipeline uses this optimization scheme to automatically design flexible tools for manipulating objects in the environment.

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II. System Pipeline

Figure 1 gives a step-by-step overview of our system pipeline for the automated design of flexible wire tools for robotic caging. Our system pipeline consists of two primary components: **1)** designing a tool and **2)** caging an object.

A. Designing a Tool

The design of the tool starts starts with the selection of "start" and "end" points for the tool (flexible wire) on the object face most accessible to the two manipulators. These start and end points lie on the outer edge of the object, which will be determined through computer vision. A path between these two points is then traced over a 2-D top-down outline of the object to get a desired shape for the tool when "closed".

That shape is then welded to two lever sections and pulled open by 125% of the object's longest chord perpendicular to the tool use axis. Our geometric optimization scheme (which builds off of work in [1]) then generates the post-expansion tool shape from these lever positions. This is then used as the final design for the wire. In order to bend the wire into the target configuration, the design will be segmented into a series of curves, each with a position, arc length, and radius about

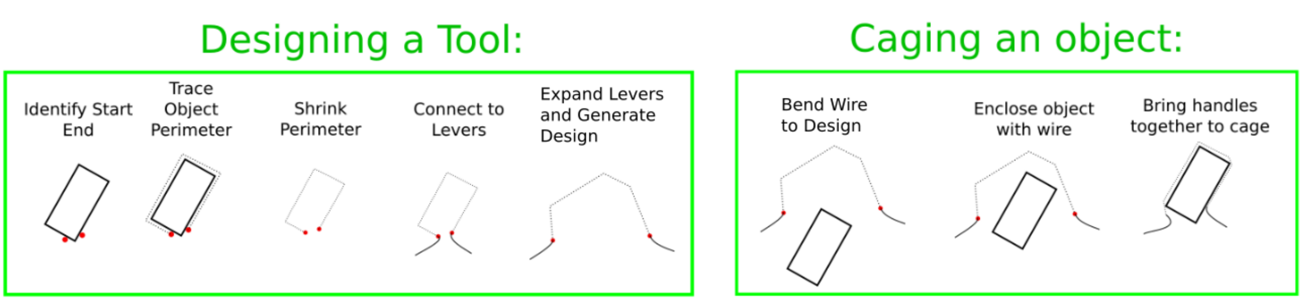

Fig. 1. **Designing a Tool and Caging an Object:** A breakdown of the steps involved in designing and using a tool based on the target object's outline. Once the object has been caged additional inward force can be applied to the wire "handles" (levers) to constrict the shape and achieve form closure.

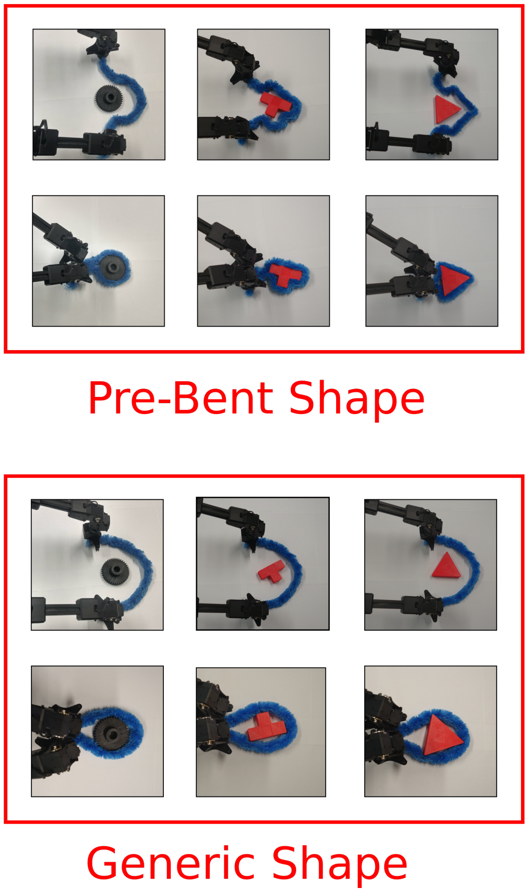

Fig. 2. **Real-World Tool Shapes for Caging:** These photos compare an arbitrary tool design to the output from our optimization scheme (we manually bent the wires here for demonstration purposes). The manipulators holding the optimized tool designs have more control over the object due to increased contact than the manipulators holding the arbitrary tool designs.

a centroid from the previous bend. Future work (covered in Section IV) will develop a method for performing this bending in the real-world using a pair of robotic manipulators.

B. Caging an Object

The opening of the tool (the distance between the start and end positions of the tool) that is generated via our geometric optimization scheme is able to fit around the target object from either the top or side. Once the object has been enclosed, the robot end effectors will then bring the two end points of the rod "closer" together by 25% of the object's longest chord perpendicular to the tool use axis in order to cage the object. For more precise control, the end effectors can further tighten the tool to achieve form closure. The manipulators can now move with fixed relative positions to change the position and orientation of the object without losing control over it.

III. Discussion

In this section, we discuss some of the finer points of our system pipeline for automated tool design, as well as preliminary results.

A. Manipulation with Automated Tool Design vs. Arbitrary Curves

Figure 2 shows a comparison of an arbitrary tool curve shape and a tool designed by our optimization scheme (currently bent by hand for demonstration purposes). The tools designed by our optimization scheme have more points of contact with the object than the arbitrary designs, which gives the robot manipulators more control over the object.

B. Perturbing End Points for Caging Designs

The tool designs output by our geometric optimization scheme are perturbed at their end points during two different steps in our system pipeline: first, after the outline of the target object has been determined, and second after our optimization scheme outputs the desired design. The magnitude of the perturbations during these steps is arbitrary (125% and 25%), but may vary according to tool design and the material of the tool being used. These perturbations are needed so that the robot manipulators can fit the designed tool over the object (and adjust the design as needed once it is in contact).

IV. Conclusion

We have presented a method for automatically designing robotic caging tools using flexible wires. Our method uses a geometric optimization scheme to solve for a desired configuration of a flexible wire based on an object's outline. Robot manipulators can then use the resulting tool to control an object's position and orientation through caging. We numerically perturb the wire endpoints after determining the outer boundary of the target object. This creates a caging tool for the robot manipulators to fit around the object. The tool endpoints can then be brought together to cage the object.

In future work, we will design a trajectory planning pipeline to enable a two-arm robot manipulator to bend the wire tools according to our optimization scheme outputs. We are also interested making the bending planning pipeline closed-loop: the robot manipulators will receive feedback on the real-world configuration of the wire (i.e., through a camera or force/torque sensing [3]) during bending and adjust their plan for subsequent bends.

References

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