A Fully Integrated Gripper Optimization System

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I. INTRODUCTION

Robotic grasping has become essential to the modern economy. In manufacturing, distribution, medicine, research, and nearly every other industry, robots perform indispensable work that is either too dull or too difficult for humans. But even as robotic technology rapidly advances, the primary method through which robots interact with their surroundings remains much the same: robotic grasping.

Robotic graspers are familiar in these industries, and they come in two main varieties: the first is the expensive, sleek, pre-packaged robotic gripper, which aims to perform a variety of tasks with one interface. These grippers often operate using proprietary software, and are robust, but limited in their versatility and flexibility. The other gripper type is the single-purpose gripper: an end effector produced through a long and expensive design process for one specific application. A single-purpose gripper excels at its task, but is limited completely to that application. With these grippers, a new part on the assembly line or a different application requires a complete, and often costly, redesign.

These gripper types are clearly limited: they are expensive and proprietary, with little versatility. But with the advent of widespread and affordable 3D printing, robotic graspers have become more accessible and flexible. Now, small companies and research labs can 3D print components to assemble a gripper inexpensively, quickly, and in-house. Despite the opportunities provided by this new technology, these 3D printed grippers fall into the same two categories as other grippers: one-size-fits-all, or single-use.

3D printing allows different iterations of grippers to be manufactured rapidly and with little labor. In order to fully leverage the capabilities of this manufacturing technology, graspers should be specialized for each specific application. However, this specialization still requires a time-consuming design process from the bottom up. Presently, there is no way to rapidly and inexpensively design and 3D print a specialized and optimized gripper for a specific application.

To address this issue, this paper presents a system to automatically optimize and design a 3D printable gripper for a specific grasping use. The system takes as inputs the application criteria: the size, shape, and weight of the object to be grasped, as well as its grasping orientation. And the system produces 3D-printable solid-modeling files for the optimized gripper; all of the parts can be printed in one print, and the only assembly required is the snapping in of servomotors.

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II. METHOD

To produce a gripper optimization system to address this issue, we first develop a base gripper to optimize, based on the literature. Then, we parameterize this design according to chosen optimization parameters, and mathematically model the gripping scenario. The system is then integrated to plug user inputs into the mathematical gripper model, produce the optimal parameters, and apply these parameters to the parameterized design to create printable, optimized files.

A. Base Gripper Design Selection

From the literature [1][4], we selected a one-size-fits-all grasper designed for 3D printing – the Yale GRAB Lab Model T42 – which will serve as a base design, or control, to be optimized. The Model T42 is a two finger pinch-style grasper, with two joints in each finger, and one actuator controlling each finger. The gripper is referred to as underactuated: instead of one actuator controlling each joint, the finger is actuated by a single servomotor that pulls a tendon to flex the joints, simplifying control and making the gripper more compliant. The grasper has several varieties, denoting the types of "connective tissue" in the proximal and distal joints in each finger: pivot-pivot, pivot-flexure, and flexure-flexure (Figure 1A).

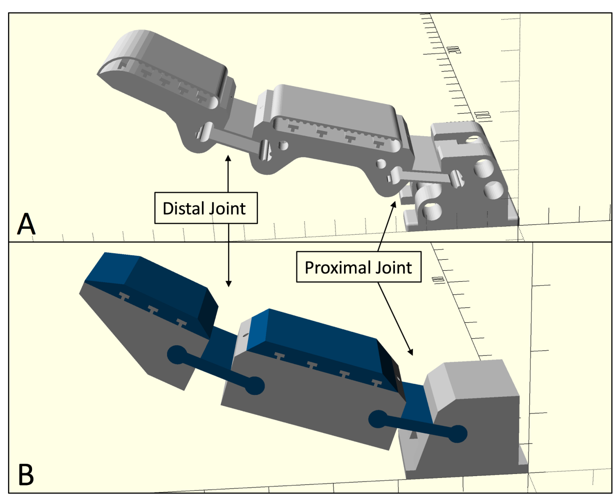

Fig. 1. A: The 3D model of the original flexure-flexure T42 finger
B: The 3D model of the modified and parameterized gripper finger

The desired qualities of the base gripper are easy manufacturability and simple parameterization. In order to fulfill these requirements, the flexure-flexure T42 gripper was re-designed to be 3D printed very simply: in the original T42, the mold is printed, silicone is poured into the mold, and then the mold walls are cut away. But in the redesigned gripper (Figure 1B), each finger can be printed (all three segments) in a single print using a dual-material 3D printer, and the entire gripper can be assembled quickly, using only two bolts. Additionally, the redesign was created using OpenSCAD, an open source 3D modeling program that can be controlled externally using scripting. Because the flexure-flexure redesign is easily parameterized, with the thickness of the joints corresponding directly to physical parameters of the gripper, external program scripts can easily generate models with variable properties.

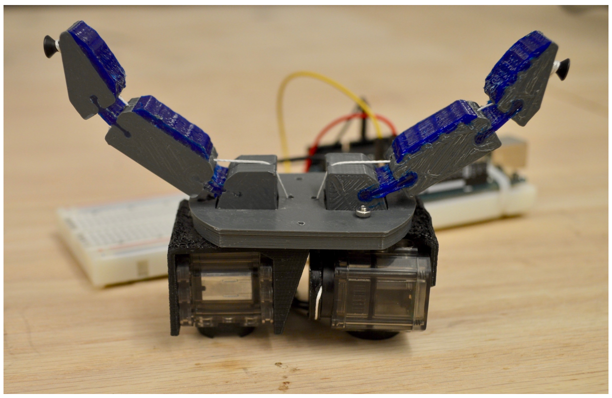

Fig. 2. The fully assembled modified and parameterized gripper. This gripper has a scaling parameter of 0.5: it is half the size of the T42. The servos underneath the gripper are two Dynamixel XL320 servomotors.

B. Development of Gripper System Model

To develop an optimization scheme for the gripping scenario, criteria must first be selected to form the objective function of the optimization problem. For our model, a linear combination of two criteria is chosen: the first is maximum error in object placement for a successful grasp. This criterion represents the robustness required for a gripper in an unstructured environment. The second criterion is grasp stability, which is represented by the magnitude of the resultant force from the normal forces exerted on the object by the gripper. A high magnitude resultant force means that the less reliable friction forces must contribute significantly to the grasping of the object, resulting in an unstable grasp.

After choosing the criteria for which the gripper is optimized, the parameters to be varied on the gripper itself must be chosen. For our model, we chose two ratios that heavily impact our optimization criteria: the ratio of the spring constants of the proximal and distal joints on each finger, and the ratio of the lengths of the proximal and distal links. These ratios can be easily varied in the design, by simply changing the thickness of the flexible “connective tissue” of the fingers, and by changing the link lengths, respectively.

Once the optimization criteria and gripper parameters have been selected, a model must be developed to simulate the grasping scenario. Our model (Figure 3) is based on A. Dollar et al. [2][3], and makes several key assumptions: first, it is assumed that the object initially contacts the gripper along the length of a proximal link. Second, this link is assumed to remain stationary and in contact with the object while the gripper is actuated. Third, the object itself is assumed to be of simple 2D geometry. The mass of the object is not integrated into the present model, but it will soon be added.

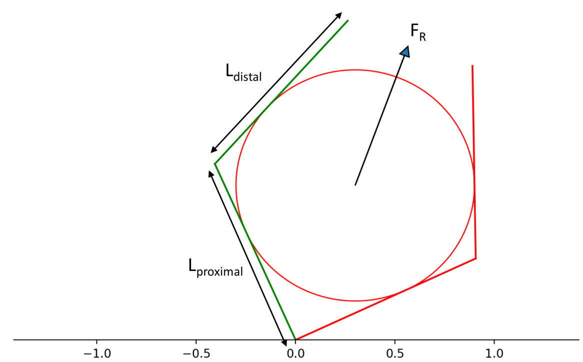

Fig. 3. Graph of a sample calculation of grip geometries and properties using the model

Using this set of assumptions, joint positions and forces for a successful grasp can be calculated using simple kinematics and geometry. Essentially, the model serves as a function for calculating grasp quality using object shape, s, the link length ratio, r_L, and (modeling the flexible joints as springs) the joint stiffness ratio, r_k:

$$r_L = \frac{L_{distal}}{L_{proximal}} \tag{1}$$

$$r_k = \frac{k_{distal}}{k_{proximal}} \tag{2}$$

This function outputs the maximum object displacement (positioning error) that results in a successful grasp, x_{max}, and the resultant force of the link normal forces, F_R, as shown in Figure 3. The relative weights (C_1,C_2) from the objective function are then applied to these values to produce a scalar quantity representative of grasp quality.

$$C_1 x_{max} + C_2 F_R = f(s, r_L, r_k) \tag{3}$$

Equation 3 is the evaluation of the objective function at a specific set of parameter values. Using this equation, a simple numerical optimization algorithm can be used to determine the optimal values of r_L and r_k. Because of the efficiency of the model calculation and the low number of variables, even computationally expensive, highly thorough optimization algorithms can be used. Given the proven accuracy of the model for a wide variety of gripping scenarios [2][3], this optimization, once implemented, is expected to be highly effective.

C. Assembly and Front-End Integration of Program

The final step in system development is to create a front-end user interface and a structure that integrates the foregoing components into a cohesive, fully automatic program. The proposed front-end will use the mass of the object to be grasped, and a series of photos taken against a calibration grid. Using simple computer vision techniques, the 2D profile that will be grasped can be extracted, and translated into an approximate geometry to be used in the optimization steps. The output of the optimization step can then be inputted into the parameters of the OpenSCAD model, to generate 3D printable .STL files for the user.

III. METHODOLOGY FOR SYSTEM TESTING

Once the system has been fully integrated, testing is simple. First, a set of test objects will be selected. This set will include objects for which the original T42 gripper is designed: objects of mid-range size and mass, with aspect ratios near one and relatively rough surfaces. However, it will also include fringe cases for which the control gripper may not be as effective: high aspect ratio objects, and objects with low densities. These types of objects are prone to failed grasps; it is easy to mis-balance a high aspect ratio object, and it is easy to push a low-density object around without successfully grasping it.

Using the set of test objects, the control gripper will be tested automatically. The gripper will be attached to a high-accuracy robotic arm, and the object placed nearby. An external vision system using an inaccurate camera will detect the object, and send open-loop commands to the robot arm, which will navigate to the object, and attempt to pick it up. This open-loop system is intentionally error prone: its controlled misalignment simulates the imperfect approaches and position information that a robot is subjected to in any grasping scenario.

After the object is grasped, the success of this grasp can be evaluated in two ways. Firstly, by simple binary observation of the success of the grasp, and secondly, by determining the security of the grasp. This is accomplished with a subroutine that shakes the arm, dislodging any object from an insecure grasp. After these evaluations, the object will be released automatically and allowed to come to rest in a new, random position, and the grasping process can be repeated for a statistically significant number of trials.

The set of test objects will be fed into the optimization system, and the optimized graspers will be printed and assembled. Then, these grippers will undergo the same testing as the control gripper, and the results compared. These testing methods will accurately simulate performance in real-world applications, where position and object information is not always completely reliable. Through these methods, the optimization system can be objectively evaluated.

IV. APPLICATIONS

An effective, open source gripper optimization system has far-reaching applications. In small companies in the manufacturing and product delivery industries, the system can be used in conjunction with an inexpensive 3D printer to produce optimized grippers for every object handling application.

In academic research and in research and development divisions of companies worldwide, the system can be implemented to not only make grasping more effective, but to standardize it. Using the system, a grasper will be optimized for each object and grasping scenario, so grasping methods and control algorithms can be compared across object type.

In commercial service applications, robots often handle a specific object type in an unstructured environment. The optimization system can be used to optimize the grasper for a home robot to pick up tools or cleaning supplies, or for a construction robot to handle objects from wooden beams to wood screws.

In all of these applications, the gripper can be produced quickly and inexpensively. Because all gripper designs produced by the system will use the same servomotors, the grippers can be built with only material cost: less than \$3 for a mid-size gripper.

V. CONCLUSION

By modifying an existing 3D printable gripper design, creating a model and optimization system for the model, and integrating these with both a parameterized 3D design of the gripper and a user interface to gather information about the object to be grasped, a novel optimization system can be created. Already, an effective parameterized gripper has been developed that can be 3D printed and assembled quickly and efficiently, and a mathematical model for this gripper has been developed for use in an optimization process. Additionally, all parameters and criteria for this optimization have been selected, and are easily implemented on the gripper. With the development of the optimization algorithm and the front-end software, a complete gripper optimization system will exist, capable of providing a simple and rapid method for producing a more effective gripper.

VI. FUTURE WORK

After the system has been demonstrated to be effective, its expansion follows a natural course. First, new gripper types can be added; instead of a system that returns a single gripper design with optimized parameters, the system could select the best type of gripper for a specific application, and optimize the parameters for the chosen gripper.

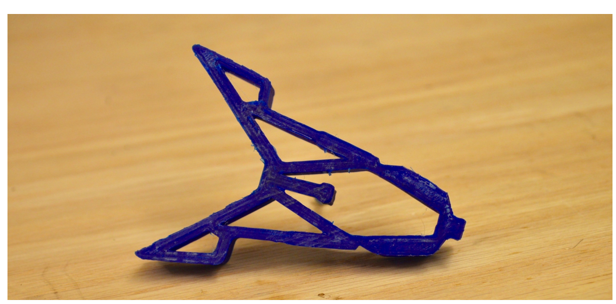

Fig. 4. An example of another 3D printable grasper type that could be implemented in the optimization system, modified from Petkovi et al. [5].

Additionally, different manufacturing methods could be explored: laser cutting and metal 3D printing could produce grippers that are not only fast and simple to manufacture, but that rival their commercial counterparts in robustness and strength. Finally, the underlying model could be expanded to support more complex geometries, and to require fewer assumptions about the movements and force interactions in the gripping process. This would result in more accurate modeling, and more finely tuned parameter choices.

REFERENCES

[1] Dollar, A. M., & Howe, R. D. (2005). Towards grasping in unstructured environments: grasper compliance and configuration optimization. Advanced Robotics, 19(5), 523543. http://doi.org/10.1109/IROS.2003.1249683

[2] Ma, R. R., & Dollar, A. M. (2014). Linkage-Based Analysis and Optimization of an Underactuated Planar Manipulator for In-Hand Manipulation. http://doi.org/10.1115/1.4025620

[3] Dollar, A. M., & Howe, R. D. (2006). Joint Coupling Design of Underactuated Grippers

[4] Ciocarlie, M., & Allen, P. (2010). A Constrained Optimization Framework for Compliant Underactuated Grasping

[5] Petkovi, D., Pavlovi, N. D., Shamshirband, S., & Anuar, N. B. (2013). Development of a new type of passively adaptive compliant gripper. http://doi.org/10.1108/IR-12-2012-452