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# A handy new design paradigm

**B. Bergelin, B. Slaboch, J. Sun, and P. A. Voglewede**

Department of Mechanical Engineering, Marquette University, Milwaukee, Wisconsin 53233, USA

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**Abstract.** In light of technological advances, researchers have lost sight of robotic grippers/end effectors design intent. In a semi-structured environment the biomimetic approach is impractical due to the high complexity of the mechanism and control algorithms. Current industrial grippers are robust, but lack the flexibility that allows for in hand manipulation. The authors believe that underactuated grippers provide the best approach to allow for in hand manipulation along with being rugged enough for an industrial setting. Thinking of the robotic gripper and the robotic arm as one system (as opposed to two separate subsystems), one is capable of using the degrees of freedom of the robot in conjunction with that of the gripper to provide the desired motion profile without the complexity of running two subsystems. This paper will outline where recent grippers have failed and will introduce a new design paradigm for grippers along with several underactuated gripper ideas.

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## 1 Introduction

Researchers have focused on replicating human dexterity for unstructured environments, like those of prosthetic hands and humanoids. Due to the immensity of this task, researchers typically have divided this field into robotic "arms" and "hands". The work on such grippers has been further divided into subcategories: grasping, manipulation, and the mechanical and algorithmic designs of both of these.

This discrete approach is inherently flawed. While much work has gone into optimizing and understanding these subfields, the overall goal of creating a system to pick up and manipulate objects has been somewhat lost. The subfields have been sub-optimized, and as such each subsystem must contain actuators and sensors that do not depend on the other subsystem. For example, when manipulating an object using finger gaiting, an excess of fingers must be used to ensure that the remaining fingers fully constrain the object while the degrees of freedom (DOF) of arm remains un-utilized. When combining the solutions from each subsystem, the result is a complicated, high DOF system with multiple sensors, algorithms, and control structures which is not practical for most applications.

While one may be tempted to say the best approach is to design the entire system holistically, the task is too large for any one research group to tackle. A better approach is to narrow the scope of the problem and fully integrate the capabilities of each subsystem together. Thus, for this paper, we consider structured and semi-structured environments (like those in industrial settings) which would allow the research to focus on several routine tasks. We also focus on the design of end effectors (admittedly a discrete approach), but one that inherently views the gripper as a mechanism that must work with the robot arm (instead of simply attached to it), with its environment (instead of simply in it), and with the object (instead of simply working on it). Inherent in this design paradigm are grippers which are simple, robust, and functional.

In Sect. 2, this paper will first review the state-of-the-art grippers and show how the current biomimetic paradigm aggravates this approach. Section 3 illustrates a further explanation of this new design paradigm and its basic tenets. We will then introduce some rudimentary grippers that are a step in the right direction in Sect. 4. In Sect. 5, it will be discussed how the prototypes implement the new paradigm. Section 6 concludes with an explanation of the potential research areas that arise from this approach and from the elementary designs.

*Correspondence to:* P. A. Voglewede
(philip.voglewede@marquette.edu)

## 2 Background

Many impressive robotic/prosthetic hands have been designed (for some historical reviews see Okamura et al. (2000); Bicchi (2000); Boubekri et al. (2002); Mason et al. (1985); Kato et al. (1987); Mason (2001)). The most notable include the Utah/MIT hand (Jacobsen et al., 1984), the Salisbury Hand (aka the Stanford/JPL hand) (Mason et al., 1985), and the IOWA hand (Yang et al., 2004). All of these hands have taken a very biomimetic approach to the problem. They consist of a fixed palm with movable fingers. Other research has focused on more rudimentary hands including the NYU hand (Demmel et al., 1988), the planar STYX (Murray et al., 1990), the Barrett Hand (Townsend, 2000), and a similar hand introduced by Biagiotti et al. (2003). These hands are suited for the grasping and manipulation of unknown objects using a variety of different grasp types (Cutkosky, 1989).

In these devices, manipulation of the object is typically done in one of two ways: finger gaiting (moving the fingers around the exterior of the grasped object while maintaining a stable grasp) or regrasping (placing the object on a surface and picking it up again). Each technique is inherently slow and requires extensive computational power to be implemented. While the engineer has been able to mimic the human hand in a kinematic sense, these designs fall short in developing a robust system capable of surpassing the capabilities of the human hand. Once again, the suboptimized hand does not work on solving the entire problem.

These hands can be contrasted to industrial grippers where simplicity and robustness are key. Some of these include those introduced by Tella et al. (1982) and Brown et al. (1999) (similarly by Balan et al., 2003). While these grippers are easy to use, they are purely for grasping with very limited manipulation. In the semi-structured industrial environment, these grippers work very well. While they do not allow for complete manipulation of the object, they do provide a fast and efficient method of grasping parts.

In order to circumvent the problem of high DOF systems, underactuated grippers have been developed. The recent work on underactuated grasping is a step in the right direction of creating a better system. Underactuated grasping recognizes the inherent problem with traditional approaches and creates grippers that decrease the number of actuators. Most of these approaches combine joints of a "finger" together with "tendons" and/or springs to give the "fingers" the capability to form to the grasped object shape. This reduces the DOF of the end effector, but does not allow it to be manipulated. Some rudimentary manipulation is gained by rolling on the fingers, but this is limited.

The future of grasping (and underactuated grasping) is a recombination of grasping and manipulation. Some initial work has involved using passive joints in conjunction to simultaneously grasp and manipulate. Several such devices are a fur picking gripper (Doulgeri et al., 2002), a pivoting gripper (Carlisle et al., 1994), a low friction gripper (Goldberg et al., 1992, 1993), and a postal bag gripper (Kazerooni et al., 2004). These grippers allow for some limited manipulation combined with the grasping task.

## 3 Proposed new philosophy of grasping

While the existing work in grippers is admirable, the future of grasping and manipulation lies in integrating the gripper into the system to which it is attached and its environment. The new philosophy of grasping and manipulation we are proposing consists of five major tenets:

1. *An effective robotic end effector does not necessarily need to look like a human hand.* This is consistent with a move away from biomimetics to bioinspiration. There needs to be a renewed focus on understanding the problem and moving away from prostheses and humanoids where form trumps function. This tenet needs to be prevalent throughout the research.

2. *In order to make an effective robotic end effector, the number of DOF must be minimal.* While technology has shown greater capability to handle larger number of DOF, this cannot be used as a crutch to lead one back to burdensome designs. Too many designs assume that multiple actuators and joints can be easily managed. Time has always shown the "keep it simple" method is most effective.

3. *The end effector should be assumed to be on a robot arm.* While this tenet may appear obvious, most end effector designs do not use the arm other than a positional device to locate the end effector. The DOF of the end effector can be decreased if one assumes that the robot arm can play a role in the grasping and manipulation.

4. *The grasped object and the environment are integral parts of the system.* Current thought immobilizes the object and then manipulates it. However, the object itself has properties which allow it to be more easily grasped and manipulated. For example, the center of gravity of an object can be utilized as a force for manipulation. Additionally, the environment offers fixed structures to which the hand can be used to move the object.

5. *The end effector structure must possess multiple functions.* Current end effectors typically have specialized the function of each structure (fingers provide a point contact). However, in underactuated grasping, the "fingers" can provide point contact as well as an enveloping grasp. This dual functionality is critical to the design of new end effectors to decrease the number of DOF.

In this new philosophy, we have created what we believe to be some steps in this direction.

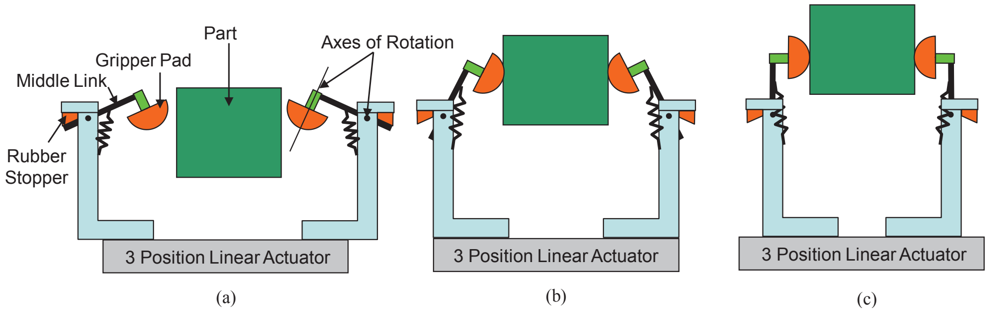


**Figure 1.** Parallel jaw gripper with singularities.

## 4 Preliminary work in this paradigm

This section will outline the work done at Marquette University in terms of this new paradigm.

*Idea 1: Parallel Jaw Gripper with Singularities*

In many applications, one needs two different motion profiles. For example, one may need translation followed by rotation. In this design (Fig. 1), a part is approached as in (a), and the part is gripped as in (b). Due to the rolling contact at the fingers (consider each gripper pad as a wheel), the part can move in or out of the page rolling on the gripper pads. When the linear actuator moves to configuration (c), in which the mechanism encounters a singularity, the part is no longer allowed to translate, but rotation is allowed around the axis between the point contacts. A prototype of this design is shown in Fig. 2.

The actuator only needs to have one DOF, and even further, only needs three positions to perform the operations. There are passive joints outfitted with springs that provide the necessary contact forces to ensure that the part does not slip. Thus, much like classical underactuated graspers, there is a coupling between the DOF and the object.

The issue with such an approach is how to provide the motion to the object since there is no actuation on it. This can be done using an external fixed finger and the remaining six DOF of the robot on which the end effector is attached. Thus, in total, there are seven DOFs that need to be controlled drastically decreasing the *total* DOF of the system. Therefore, the system DOF is decreased and the system performs the same operation. Additionally, the grasp and the manipulation are designed as one; they are indistinguishable in the design.

*Idea 2: Parallel Jaw Gripper with Changing Joints*

A possible variant of the design which allows for fixed positioning of the object is to modify the gripper pads such that the translational axis is replaced by planar contacts such that the block is fully constrained (Fig. 3). In the second stage (b), due to the friction between the block and the planar contacts, the block cannot move and is fully constrained. When the linear actuator is moved again, the ball bearings contact the block and due to the reduced friction as in (c), allow rotation similar to Idea 1. The force for this motion can again be provided by an external fixed finger and using the robotic arm itself. The prototype can be seen in Fig. 4.

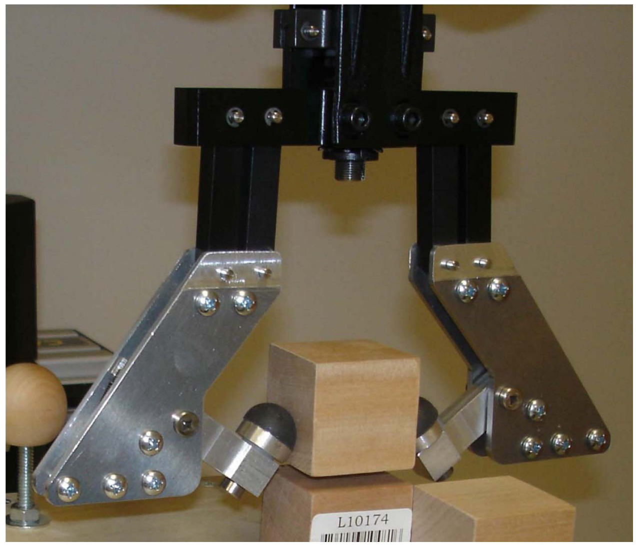


**Figure 2.** Prototype of parallel jaw gripper with singularities.

The design is modular in that it can allow different types of motion by a simple end effector change. While this is not ideal for unstructured environments, it is very feasible from an industrial standpoint. The end effector can be changed for different parts easily and allows for quick manipulation of the object without finger gaiting or regrasping. This type of device can be better considered as a metamorphic mechanism.

*Idea 3: Parallel Jaw Gripper with Spring Actuated Joints*

A third variation of the design utilizes spring plungers (Fig. 5) (typically used for positioning parts in fixtures). In position (b), the spring plungers are compressed which allows for planar contacts between the part and the friction

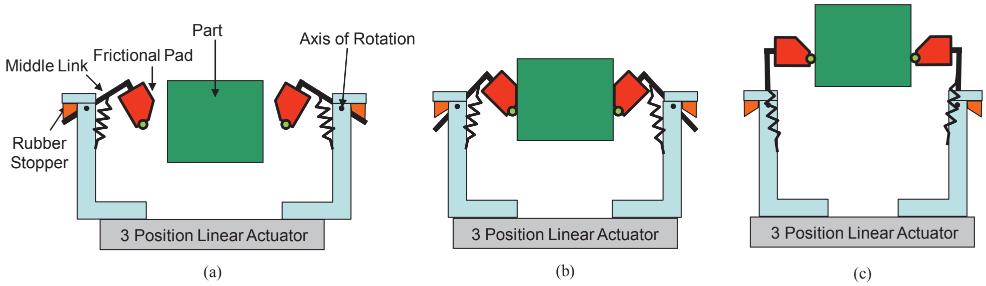


**Figure 3.** Parallel jaw gripper with changing joints.

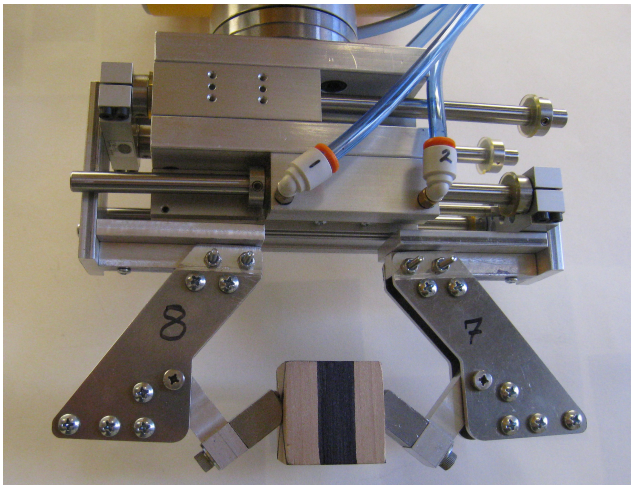

**Figure 4.** Prototype of parallel jaw gripper with changing joints.

pad. When the linear actuator is moved to position (c), a point contact is formed. The part can then be rotated using an external fixed finger or from gravitational force (depending on grasp location). The advantage of this design is that the system remains in a stable equilibrium position throughout its operation and is quite rigid. The prototype is shown in Fig. 6.

## 5 Discussion

Each of the proposed end effector designs follows the newly proposed philosophy of grasping. Rather than describing each gripper in detail, it will be shown how these novel end effectors follow this new paradigm.

1. *An effective robotic end effector does not necessarily need to look like a human hand.* While each of the grippers have hand-like components (“fingers” and a “palm”), they do not necessarily look or act like a human hand. In fact, each gripper uses linear motion of the base, as opposed to rotational actuation. This linear motion is much more typical of industrial grippers, which are designed to be simple and robust. There is also no coupled motion of the joints (typical of most underactuated grippers). The end effectors outlined in this paper, while not appearing hand-like, are robust but also retain some of the dexterity to which a biomimetic gripper may possess.

2. *In order to make an effective robotic end effector, the number of DOF must be minimal.* Complex anthropomorphic hands are inherently slow and difficult to implement due to the required computational power. Each of the proposed grippers can be controlled with a single actuator, and thus reduces the complexity of the system as a whole. The implementation of passive components allows the grippers to gain or lose DOF. The proposed designs are intended to provide the system with an added DOF which can be gained or lost without the complexity of a biomimetic hand (i.e., number of joints actuated and intricate control algorithms). The DOF of the gripper are changed solely by controlling a single linear actuator. This allows for the robustness, simplicity, and speed needed in an structured setting.

3. *The end effector should be assumed to be on a robot arm.* Attaching the end effector to a robot arm allows one to utilize the robot’s DOF when performing manipulation tasks. All of the grippers, when incorporated into the system, use the DOF provided by the robotic arm, along with the end effector’s single actuator, to achieve the desired in-hand manipulation. Also, rotation of the grasped object is provided; the axis to which the object rotates orients it from facing into the “palm” to out of the “palm”. This is typically a shortfall of most robotic systems. This idea follows closely with Tenet 4.

4. *The grasped object and the environment are integral parts of the system.* In each of the proposed gripper designs, an external fixed “finger” may be used in conjunction with the DOF of the robot to achieve the desired amount of rotation for the part. This is related to Tenet 2, as it decreases the number of actuators and Tenet 3 in that it utilizes the robotic arm’s DOF to provide this motion. In each design the grasped object and fixed finger (part of the “environment”) are critical in achieving this in-hand manipulation.

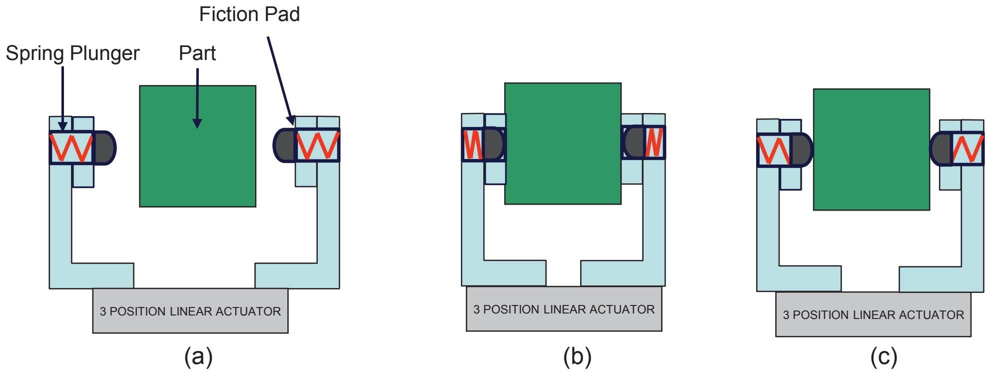


**Figure 5.** Parallel jaw gripper with spring actuated joints.

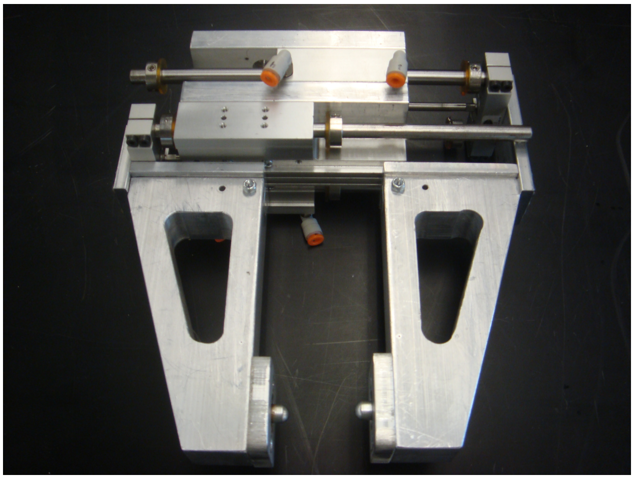

**Figure 6.** Prototype of parallel jaw gripper with spring actuated joints.

5. *The end effector structure must possess multiple functions.* Each novel parallel jaw gripper can perform multiple functions. The grippers can be used for pick-and-place operations that do not require any in-hand manipulation. In addition, the new grippers can also be used to provide rotation of a part about the gripper's contact points. Combining both of these functions into a single gripper can potentially reduce costs and improve efficiency.

While it is clear that these novel end effectors are not yet optimal, it is our belief that this method exhibits great potential for future research. The next section outlines future research directions and potential applications for the new design paradigm.

## 6 Future research directions

The future of grasping is in the development of the tools and techniques for the synthesis of these mechanisms. There exists a wealth of tools for the design of four bar mechanisms and some for other planar mechanisms. There even has been fundamental work on designing closed chain mechanisms in general to provide certain motion characteristics. However, these tools do not exist for grippers and mechanisms that change depending on their pose. Here we present specific research directions that can potentially lead to advances in robotic grasping.

1. *Synthesis of reconfigurable mechanisms*

   Reconfigurable mechanisms are those in which the DOF of the mechanism changes depending on its configuration. This paper has presented novel gripping mechanisms that utilize variable topology joints. Analytical tools such as graph theory and adjacency matrices may be used to analyze reconfigurable mechanisms but general synthesis techniques have yet to be developed.

2. *Expansion of analysis tools using screw theory*

   Screw theory has been a useful tool in the synthesis of non-reconfigurable mechanisms. Expanding these techniques to reconfigurable mechanisms could lead to significant advances in the design of underactuated robotic grippers.

3. *Motion planning algorithms*

   Current motion planning algorithms are written so that the object grasped avoids contact with obstacles as it is transferred from one location to another. However, external obstacles (i.e., a fixed finger) have the potential to aid in manipulation of an object without adding extra actuators. New motion planning techniques need to incorporate environmental factors in conjunction with the DOF of the robot.

## 7 Conclusions

We believe that there needs to be a fundamental shift in the way researchers approach end effector design for industrial applications. Unless used as a prosthesis, end effectors need not look or act as a human hand. It seems as though robotic end effectors continue to increase in complexity while their main goal remains unchanged. Through implementation of the proposed design paradigm, robotic grippers can achieve in-hand manipulation while decreasing the amount of actuators and remaining robust. By using the five tenets proposed in the new design paradigm, three end effector designs and corresponding prototypes were presented. They are simple, robust and capable of achieving their objectives through use of only a three position linear actuator. Underactuated grasping, while still underdeveloped, is a step in the right direction in designing grippers which possess the ability to manipulate objects in-hand and still maintain the durability and simplicity desired for industrial settings.

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