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Hands-on Project in a Modeling and Simulation Course: Assistive Device for Elderly

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Abstract

One common issue among old-age people is a loss of mobility or strength of their joints. This problem can ultimately inhibit them from bending over to pick things up from hard-to-reach places. A popular item that can help these people combat this issue is the long-reach grabber. This mechanism has a handle with a lever, long arm, and soft grippers at the end that open and close when you release or squeeze the lever to grab objects. The grabber can tremendously help someone that is struggling due to a lack of mobility. However, what if the person using this device also has weakness in their hands and cannot hold the grippers closed?

It is possible to keep the gripper closed with a bistable compliant mechanism. This redesigned device can achieve the same function but will be better since continuously squeezing the lever is not necessary anymore. It will make it more user-friendly than before for a person with lower grip strength.

A bistable compliant mechanism only works better for the elderly if the forces are low to activate the locking mechanism. Dynamic analysis in the CAD system determines the forces needed to open and close the bistable mechanism to verify its feasibility and its comfort level. The first step in modeling the mechanism is to create a model of the grabber with standard joints. This step is followed by converting the standard joints into compliant ones. Many different types of joints are available to convert the common joints to compliant joints. The compliant joints are kept simple to avoid modifications in 3D printing. After the dynamic simulation of the mechanism, a working 3-D printed model will be made to test the functionality of the newly designed mechanism.

This paper describes a student project in a dynamic modeling and simulation class. The design process facilitates computer-aided dynamic modeling and simulation approach and its verification. In this study, the well-known long-reach gripper design is improved to make it user-friendly for the elderly. The converted compliant to the standard joint mechanism regarding function with the added self-locking feature is designed and simulated.

Keywords: 3-D printing, assistive device, bistable, self-locking compliant mechanisms, grip strength, joints in dynamic analysis

Introduction

Compliant mechanisms are flexible link mechanisms, which gain some or all of their motion through the deflection of flexible members [1]. These mechanisms can be fully compliant or partially compliant. A fully compliant mechanism has no rigid body joints. A partially compliant mechanism has some compliant members and some non-compliant joints [2]. Mechanism designs have used deflection for a long time. For example, archery bows or catapults, use energy that has been stored in a deflected beam to propel objects across long distances. Some other uses of these types of designs are tweezers that grasp small objects and various types of springs or hinges that use deflection to achieve a desired motion [3].

An important advantage of a compliant mechanism is reducing the total number of components required to function. This reduces manufacturing and assembly time and costs [4]. Other advantages are reduced wear, friction, and backlash, corresponding to increased precision and reliability [5]. There are some challenges in modeling the mechanical properties of the compliant mechanisms [6].

The specific goal of this redesign study was to turn it into a bistable compliant mechanism. A bistable mechanism has two positions within its range of motion that are in stable equilibrium [7]. This reduces the power requirements greatly because they only require energy to switch states, with no energy needed to maintain the state [8-10].

The characteristics of a bistable compliant mechanism are what's going to be most beneficial for someone with low grip strength. Some common reasons people may have a harder time using a device, like the long-reach grabber, that requires constant force could be due to conditions like arthritis or osteoporosis. Both of these may cause issues for an individual including impairment of joint lining, bone mass, strength, and microarchitecture [11,12]. However, the operation of the device can become more user-friendly with the addition of the bistable option.

The long-reach grabber is a common assistive device used by older persons who also have impairments impacting functional performance [13]. This aids them in grasping an object that may normally be out of reach due to a disability [14]. Several factors affect the person's ability to use the device including motor coordination, visual deficits, or lack of functional range of motion [15].

A hands-on project in a modeling and simulation class is described in this paper. In this study, the well-known long-reach gripper design is improved to make it user-friendly to the elderly and analyzed to determine if people with a poor range of motion and grip strength can use the new mechanism with a bistable element. The analysis starts with modeling the long-reach grabber with standard rotational joints on CAD software. In the Pseudo-Rigid-Body approach, the rotational joints are modified with close to values of actual spring properties to simulate compliant mechanisms. The dynamic simulation of the grabber assembly was used to learn more about the compliant mechanism. The required forces are calculated to trigger the compliant mechanism. Two dynamic simulations were run to evaluate compliant mechanisms with two different spring properties, one with the values found with experiments of prototyped joints and the other one with the FEM results of the CAD models. Spring properties are estimated after the rotational dislocations are analyzed using FEM under the load. The compliant joints of the mechanism are also precisely 3D printed and tested to find the spring properties. These values were used in the dynamic analysis. This paper attempts to explain the prototyping of the mechanism in the verification of the dynamic simulation.

Projects in a Dynamic Modeling and Simulation Course

Modeling and Simulation in ME Design (ME 1063) is a dynamic system elective class for ME seniors and juniors. This course emphasizes the development of modeling and simulation concepts and analysis skills necessary to design products, mechanisms, and dynamic systems. Students will learn to model and analyze dynamic systems. They recognize the opportunities of modeling and simulation and integrate them into traditional engineering analysis and design workflows. The key emphasis is on problem formulation, model building, data analysis, solution techniques, and evaluation of alternative designs/processes in complex systems/products that change over time, not just static properties of observations. A term project offers exposure to simulation tools and provides students the context to practice their skills in a complex design environment. It is a hands-on class with computer-aided dynamic simulations. Students are also expected to design and prototype their mechanisms. A student project in this course has been reported in this paper.

Design and Analysis of the Grabber

The main advantage of the redesign is force is applied to open the mechanism (Figure 1). After the object is grasped, no force is necessary to retain it. The new design has more advantages compared to the Long Reach Grabbers in the market (Figure *2*).

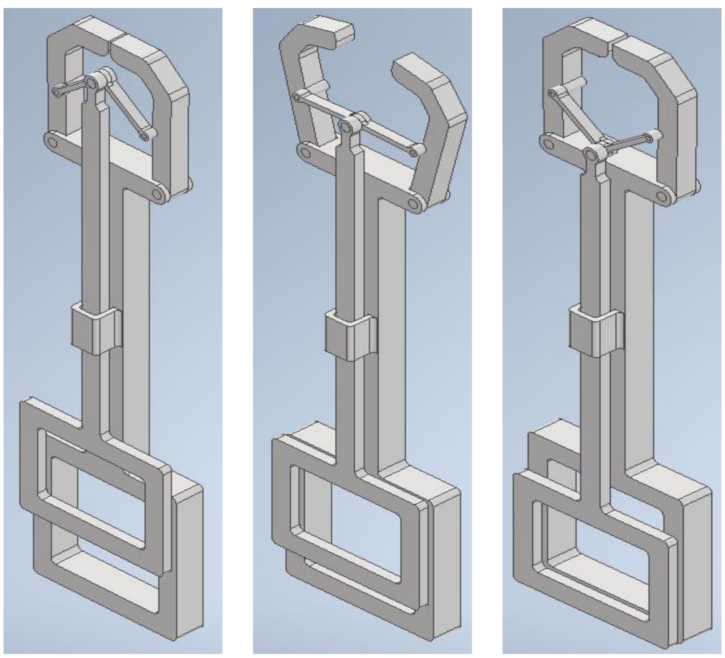

Figure 1: Redesigned Grabber with Rotational Pin Joints

Figure 2: Grabber Designs in the Market

Some of the advantages of compliant mechanisms are manufacturing time and costs. Within the procedure physical models will be made using 3-D printers and the compliant model will be easier and quicker to assemble. Another advantage is reduced wear and friction compared to mechanisms with standard joints. The disadvantages of the compliant mechanisms are sensitivity to fatigue of the flexible material and the high operation forces required.

The compliant mechanism has flexible joints. With the pseudo-rigid-body model approach, flexible joints are modeled as rigid links connected with pins and springs that represent the compliant mechanisms of resistance to motion. (Figure 3). The pseudo-rigid-body model provides an easy way to model the complex, nonlinear deflections of compliant mechanisms, which opens up the possibility of using the design and analysis methods developed for rigid-body mechanisms in the design of compliant mechanisms [16]. This approach approximates the force-deflection characteristics of a compliant segment using two or more rigid segments joined by pin joints, with torsional springs at the joints modeling the segment's stiffness. The simulations are run using the dynamic simulation model in Inventor [17] with torsional springs with different characteristics of stiffness. The following procedure for the grabbers' design and analysis is outlined in Figure 4. The purpose of this analysis was to determine if the redesigned compliant mechanism is better suited for the elderly or people with poor grip strength compared to the current mechanism designs.

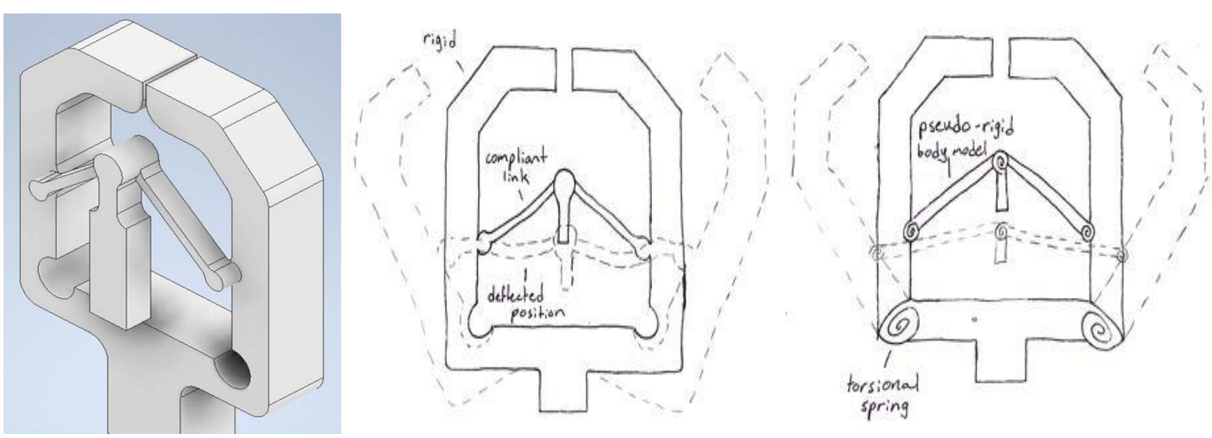

Figure 3: Redesigned Grabber with Compliant Joints and its Pseudo-rigid Body Model

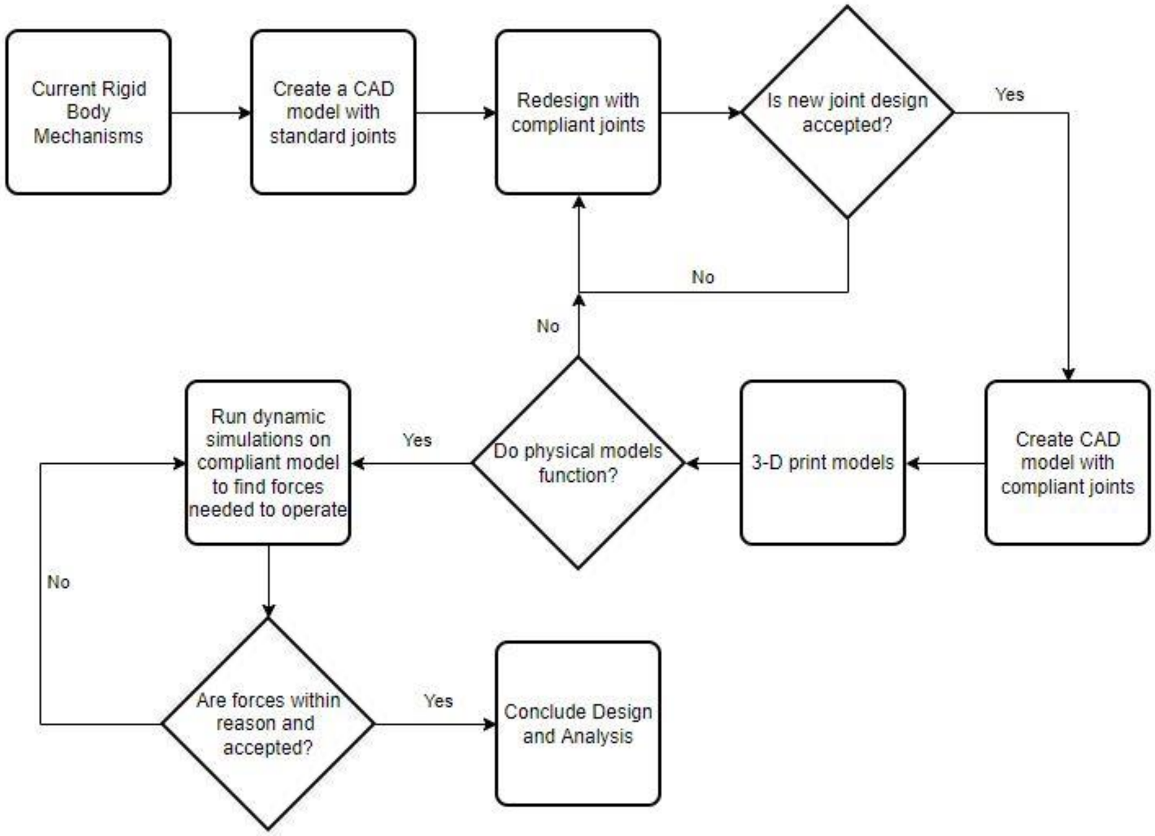

Figure 4: Design Procedure

Two frequently used rigid body designs of the assistive device were the starting point for the redesign. The joints are converted into compliant ones and the mechanism is redesigned with a reorientation of the handle for easier handling of the mechanism. Five joints are converted to compliant equivalents. Notch-type compliant joints were used. These were chosen based on this type of joint's simplicity, size, and functionality. After this redesign, the new compliant mechanism was 3D printed and tested. Two different materials were used, the handle sections and the compliant section. The rigid portions were printed in PLA and flexible portions in TPU. TPU was flexible enough while still being able to maintain its original form after repeated use. The 3D printed compliant mechanism can be seen in Figure 5. This mechanism is used in simulations to determine to force needed to operate the device.

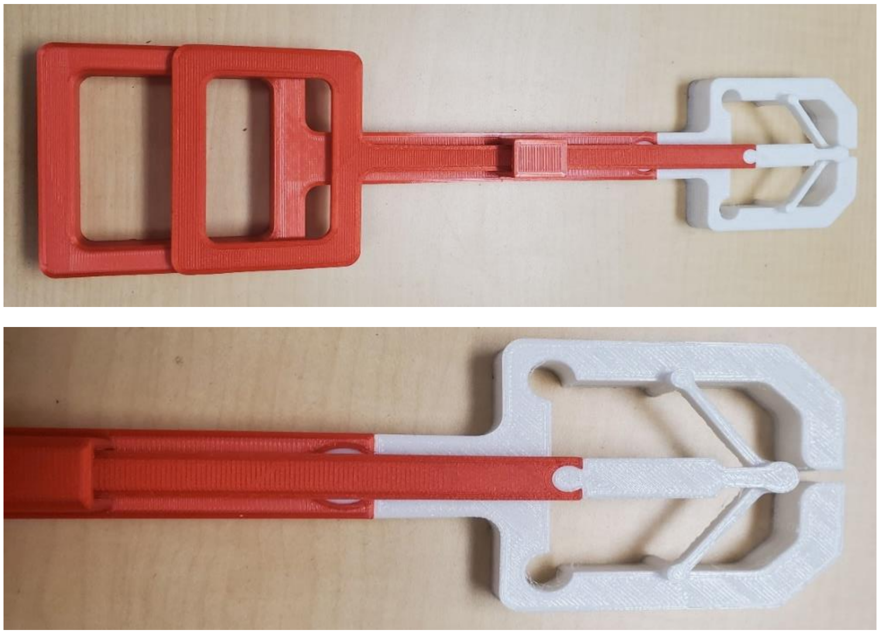

Figure 5: 3D Printed Compliant Mechanism

Dynamic Modeling in CAD System

The dynamic simulation model has been modified with torsional springs in joints to simulate the pseudo-rigid-body model approach in CAD software (Figure 7). The elastic stiffness for the torsional spring is first estimated using the material properties in the literature. These properties are not one number but a wide range of value depending on the condition of the flexible material, manufacturing, and service condition. For example, the exact properties of the material that has been used for 3D printing are slightly different than other manufacturing processes for TPU [18]. The elastic stiffness for the torsional spring is calculated using the FEM analysis and verified with experimental values (Figure 6).

Figure 6 Experimental setup to verify the results

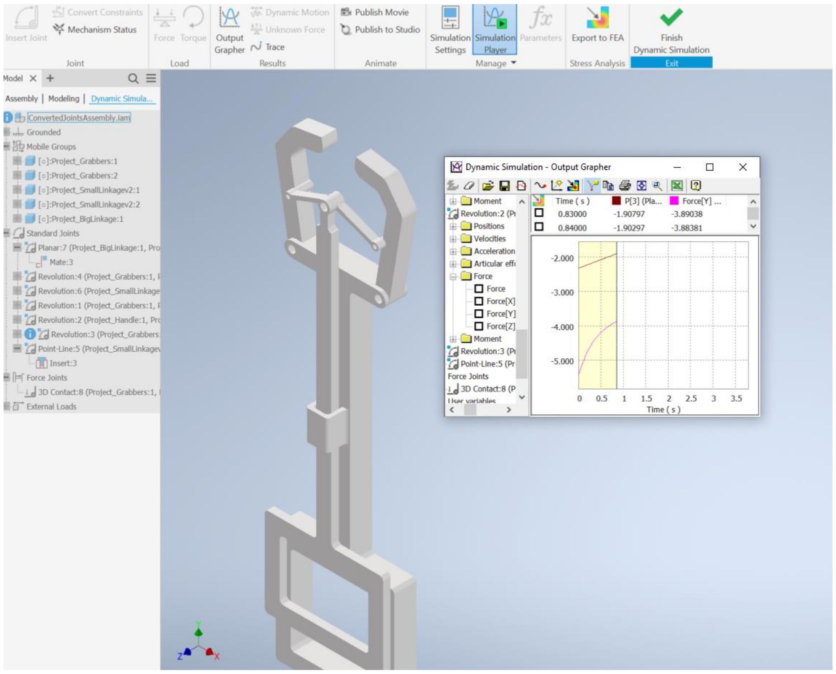

Figure 7 Dynamic Simulation in CAD System

Torsional spring stiffness K was determined by FEA analysis of the grabber (Figure 8) and used in the dynamic simulation model. Displacements in Y directions are used to find the change in the angular distortion.

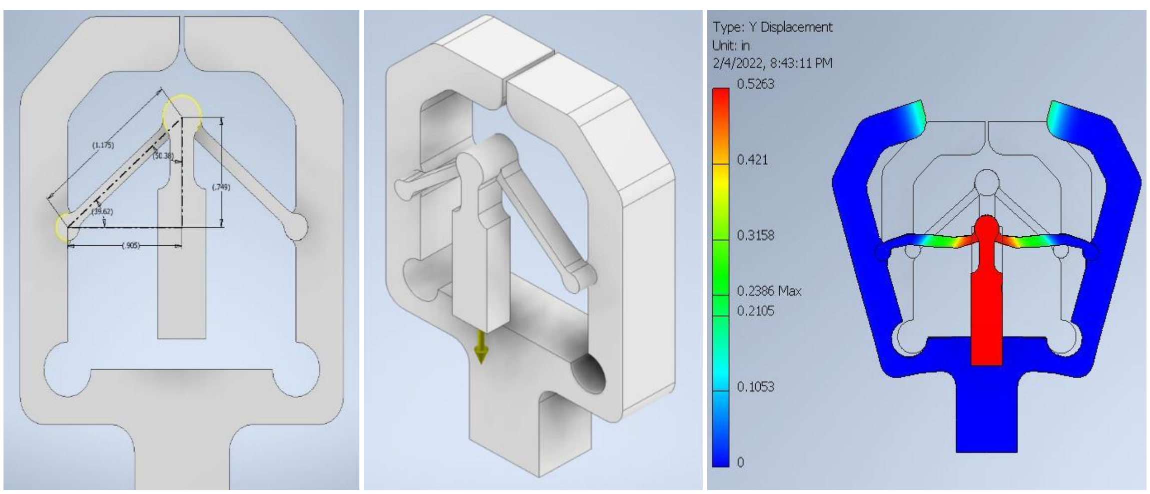

Figure 8: Modeling and FEM analysis of the Grabber

The change in the angular distortion with different loading conditions analyze by the FEM (Table 1) and the actual forces applied to the 3D printed grabber (Table 2). These results are used to estimate the spring stiffness K (Figure 9).

Table 1: Loading Conditions in FEA Analysis

Force [lbf]	Torque [lb-in]	Displacement [in]	Δθ [degrees]
0.25	0.294	0.129	7.80
0.50	0.600	0.257	15.39
0.75	0.931	0.386	22.61
1.00	1.302	0.514	29.22
1.25	1.724	0.643	35.21
1.50	2.204	0.771	40.48

Table 2: Loading Conditions in Experiments with the 3D printed part

θ [degrees]	Torque [lb-in]	Δθ [degrees]
162.16	0.143	17.84
148.15	1.104	31.85
122.12	2.286	57.88
90.70	3.461	89.30

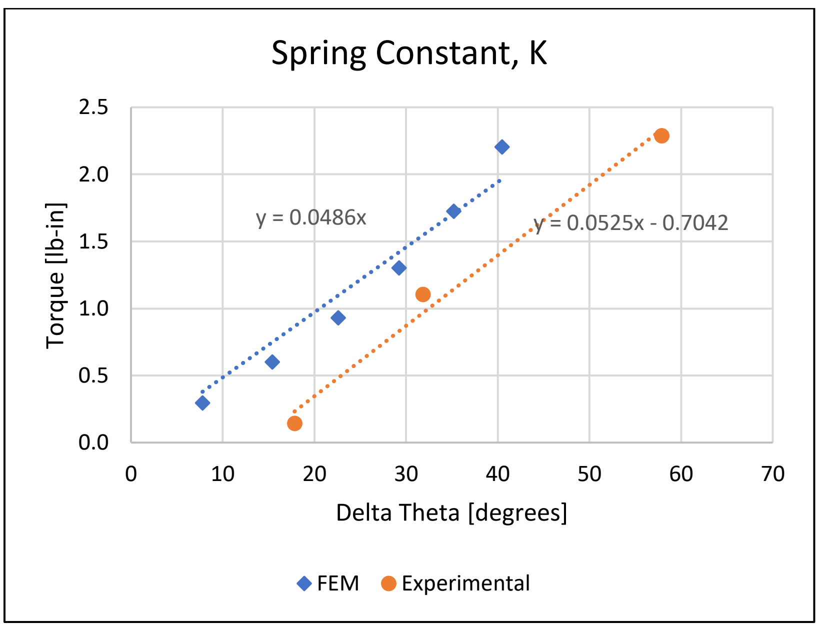

Figure 9: Spring Constant estimated from FEM and 3D-printed Part Experiments

These values were then used in the dynamic simulations of the grabbers modeled as a pseudo-rigid-body with this elastic stiffness set on each joint. The simulated forces are displayed while moving the grabbers from the initial closed position to the fully open position and back to the final closed position by the output graphs seen in Figure 10.

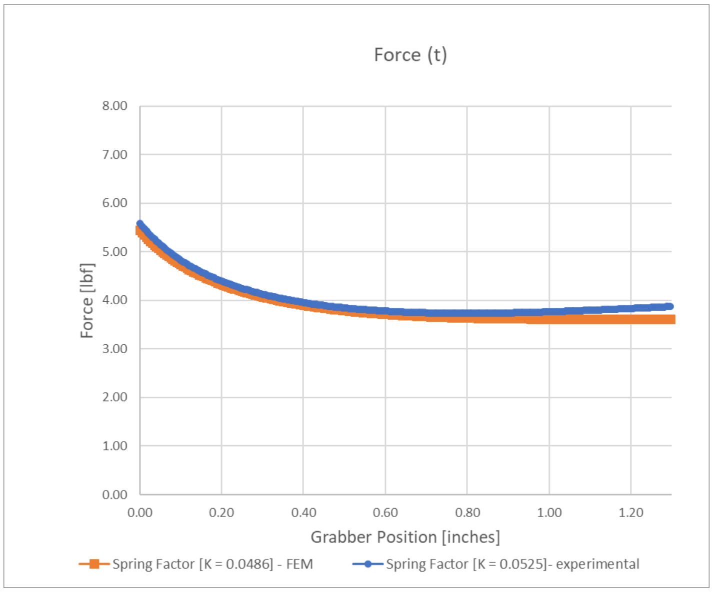

Figure 10: The Dynamic Force during the Motion (with the Spring Stiffness Constants K = 0.0486 lb-in/deg and 0.0525 lb-in/deg)

A force of 5.5 lbf is required to open the mechanism from the initial closed position in simulations. This value is close to the average force of 4 lbf measured from the 3D printed mechanism. The dynamic model could be successfully used in compliant mechanism design if the stiffness and the damping values of the standard joints in the simulation were modified to estimate the dynamic forces.

Conclusion

A dynamic simulation model has been built for a long reach grabber and used to analyze the mechanism in a senior-level elective class. The standard joints in the dynamic model have been modified to estimate the dynamic forces in the compliant mechanism. The force needed to open this assistive device was estimated at 5 lbf in simulation. Further tests of the 3D printed prototypes are needed to verify and calibrate the simulation for precise results. The 3D printed device can be operated with a finger by an average person. The variation in stiffness has been observed in 3D printed prototypes with TPU. The operation forces vary from 3 to 5 lbf when measured from 3D printed prototypes by a load cell.

The dynamic simulations in CAD systems provide a straightforward method to design and test mechanisms with compliant joints. More studies would be necessary to improve the design of the assistive device for people with poor grip strength.

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