Design of a 3D Printable Robotic Arm for In-Orbit Repairs via CubeSat Platforms

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Abstract

With the increased accessibility to space travel and orbital-based science experiments brought on by private launch providers, the ability to maintain long term orbital missions via in-situ repair and refueling has become economically viable. While large aerospace companies have the capital to expend hundreds of millions of dollars on missions such as Orbital Express and the Mission Extension Vehicle, at the university level, research into in-orbit repair is lacking, expressly due to high costs and lack of adequate technology. In contrast, additive manufacturing, otherwise known as 3D printing, has been increasing in popularity due to its accessibility in both cost and ease of use. To encourage further research into in-orbit repairs, a first of its kind, 3D printable robotic arm has been developed, specifically designed to fit within a 6U CubeSat, which undergraduate and graduate teams at CalPoly Pomona have experience with and access to. An SLA UV-Resin 3D printer was utilized to manufacture components with geometries impossible to create via traditional manufacturing techniques. In addition, topological optimization was used to ensure the components be as light-weight as possible while remaining strong enough to withstand forces exerted by and on the robotic arm. The aforementioned techniques, combined with inverse-kinematics developed in MATLAB and executed by an Arduino, allow the robotic arm to be compact enough to fold within a 3U CubeSat, while still retaining the strength to move freely and manipulate a payload.

Design

The arm must fit inside a 3U-compartment (100x100x300mm), so that the arm could be attached to a 6U satellite and be stowed in a standard CubeSat launcher.

A design consisting of modular tubes and elbows was deemed the best, due to reduced weight and increased strength of the overall structure.

The arm would fold like that of a snake coiling, leaving room for 2 further linkages which could be added due to its modular design.

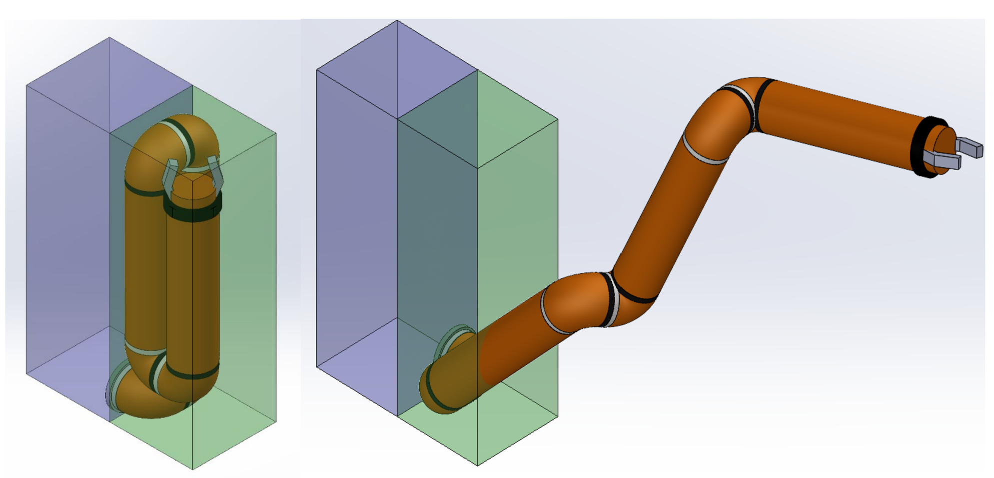

Figure 2: Robot arm stowed and deployed

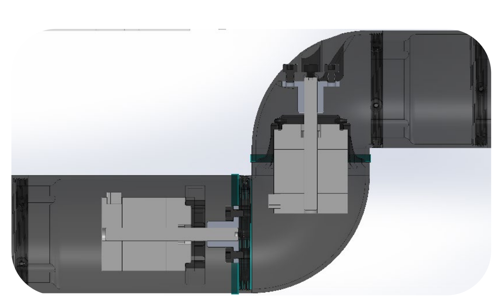

Figure 3: Cross section of a two-elbow linkage

Programming

MATLAB was the primary source of generating the inverse kinematics through the *generalizedInverseKinematics()* solver, as this was the only function capable of solving for systems with more than 6 degrees of freedom. To utilize MATLAB and the Robotics Systems Tool, the CAD needed to be converted to a URDF file via a SolidWorks addon by Steven Brawner, which contains information for each rotating joint, such as mass, location, and range of motion.

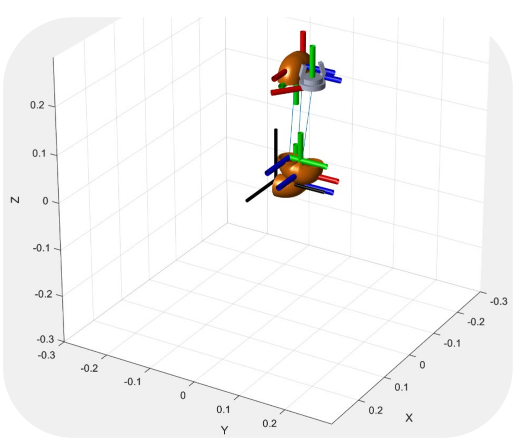

Figure 4: MATLAB model of arm stowed

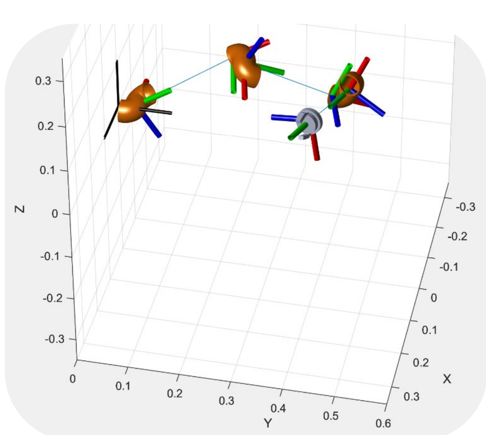

Figure 5: Inverse Kinematics Solution 1

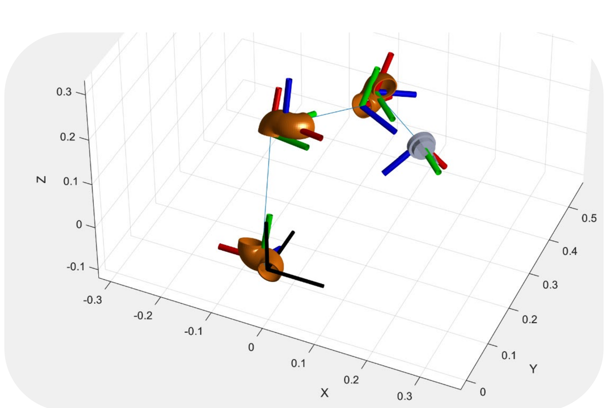

Figure 6: Inverse Kinematics Solution 2

Figure 1: Raytraced 2:1 render of "Noodle"

Manufacturing

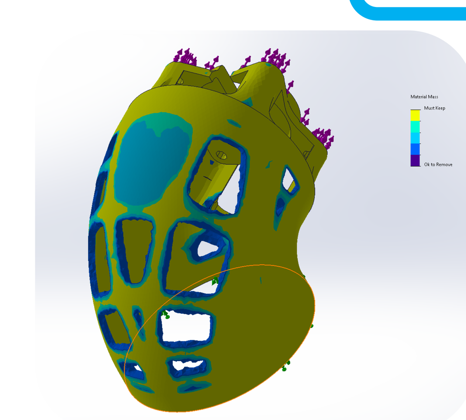

Figure 8: Topology solution with forces shown

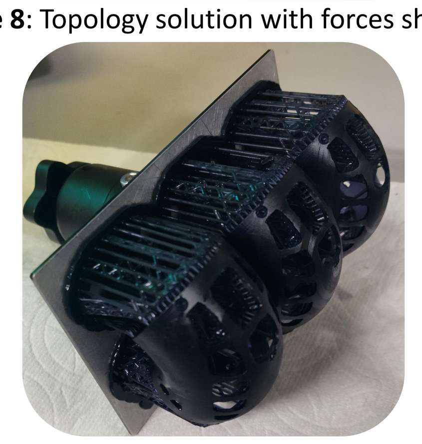

Figure 9: First batch of SLA printed parts

An SLA 3D printer with SirayaTech Nylon Black resin was used to manufacture most of the pieces. Nylon Black was chosen as the primary material due to its high tensile strength of 60Mpa and 1% shrinkage post-curing. In addition to resin, PLA on an FDM 3D printer was used in the washers between joints and the base, due to its low coefficient of friction with the resin parts.

A high-fidelity topology optimization study with simulated forces, meshed at 0.04mm was used on the two types of elbows. This resulted in reduced mass by 11%, and less resin needed to print each part without affecting the overall stiffness of the joint. Each study took about 12 hours.

Results

"Noodle" met its two main design goals of being modular as well as fitting within the 3U enclosure. However, this space reduction came at the cost of poor heat dissipation and large power requirements. The topological optimization created flawless results, and not a single part has been broken, even when accidentally stepped on.

Development for "Noodle" will continue, focusing on implementing planetary gearboxes for the motors, which will reduce power requirements and heat dissipation. As for control systems, the goal is to improve the programming to work in real time with ROS.

Prototypes

The 3D printed parts, as well as over 150 M2 screws, 7 NEMA 11 Stepper Motors, an Arduino Mega, 7 DRV8825 Stepper Drivers, and over 84ft of wiring culminated into the first prototype of the robotic arm, dubbed "Noodle".

Noodle's first rendition has had complications. The small NEMA 11 motors struggle to move the joints, and require at least 24V/5A to operate acceptably, but result in the motors reaching their max operating temp of 60C°, which just so happens to be the temperature at which the resin begins to fail.

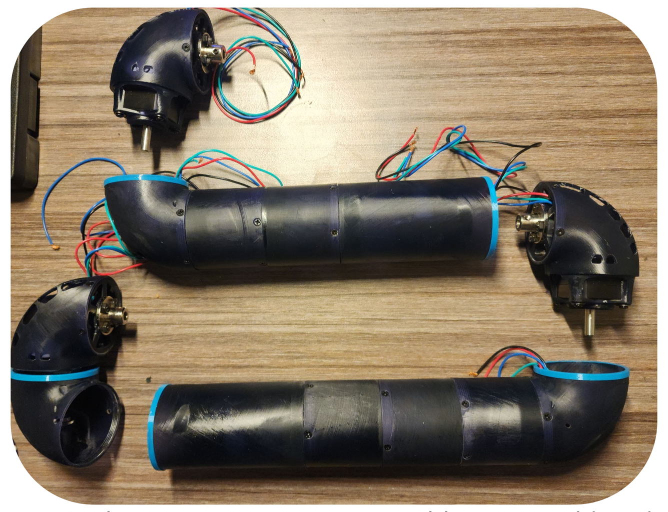

Figure 10: The components pre-assembly, wires soldered and ran through the tubes

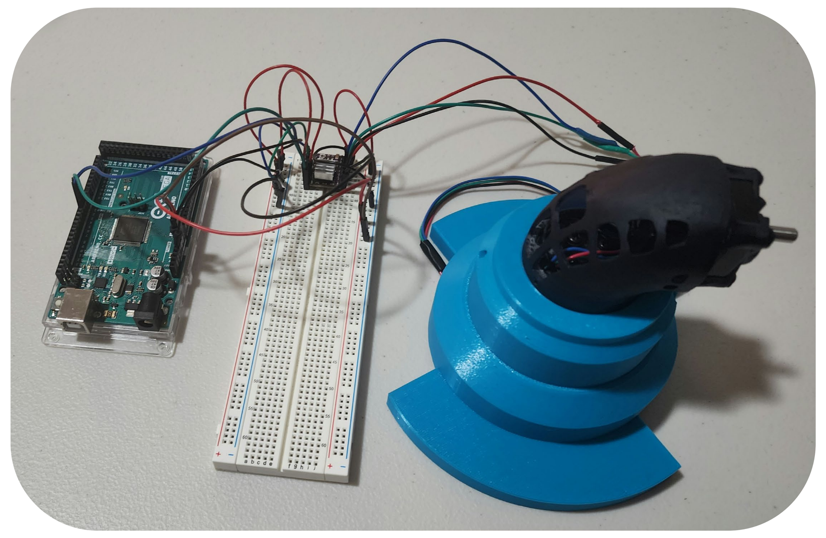

Figure 11: A test stand wired to the first stepper motor to test voltage requirements