Overhead Hose Carrying System for CubeSat Testbed

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Kellogg Honors College Capstone Project

Background

Cube Satellites, or CubeSats, are briefcase-sized satellites which are typically used to deploy small scientific instruments in a cost-effective manner. A single rocket launch can send upwards of 60 CubeSats to space, allowing for space “rideshares.” Recent advances have opened a new possibility for CubeSats: creating what are called CubeSat constellations. A constellation is a large group of CubeSats which orbit and move while staying in a pre-determined formation to serve purposes such as creating far-reaching telescopes.

The Problem

The current CubeSat model used on the CPP formation flight testbed contains an on-board compressed air tank that feeds the air bearings but has a very limited volume. Furthermore, this air tank contributes a large amount of weight and size to the CubeSat model, reducing the amount of CubeSat models which can fit on the table.

Objective

The goal of this project was to create a system that will allow air tanks to be removed from the CPP CubeSat models and be replaced by a large-capacity compressed air tank offboard the CubeSats in order to increase the duration of formation flight testing and the number of CubeSat models which can be tested.

Abstract

The Cal Poly Pomona Aerospace Department Cube Satellite (CubeSat) testbed is limited in its capability to test formation flight algorithms of CubeSats because of the short test duration and large CubeSat size caused by using compressed air tanks on-board each CubeSat. The CubeSat models used on this testbed require compressed air to levitate with air bearings, allowing them to move nearly frictionless on the testbed table. This project aimed to create the mechanical portion of a system that will allow air tanks to be removed from each CubeSat model and be replaced by a large-capacity compressed air tank offboard the CubeSats that will route air through a hose individually to each CubeSat. A prototype design referred to as the Overhead Hose Carrying System (OHCS) was created using Computer Aided Design (CAD) tools while ensuring compatibility with the motion tracking system necessary to run the testbed. In addition, a scaled-down version of the OHCS was built to test the functionality and control system prior to building the full-scale version. Although construction of the full-scale OHCS was not possible due to school and laboratory shutdown in response to COVID-19, the completed CAD and functioning scaled-down OHCS demonstrate the feasibility of the design to greatly extend both the run-time of CubeSat tests and the maximum number of CubeSats which can be used in the test.

The Solution

Overview

In order to feed a compressed-air hose to each CubeSat model as they move around, the hose must follow each CubeSat model. However, the CubeSat models must not drag the hose around, as this would have interfered with the nearly-frictionless environment in which the CubeSat models move. It followed that the hose must have its own motion system that allows it to move independently of the CubeSat models, tracking them in order to stay directly above each CubeSat model. Once this was achieved, the compressed air could be routed to each CubeSat model without creating a tugging force on the CubeSat model.

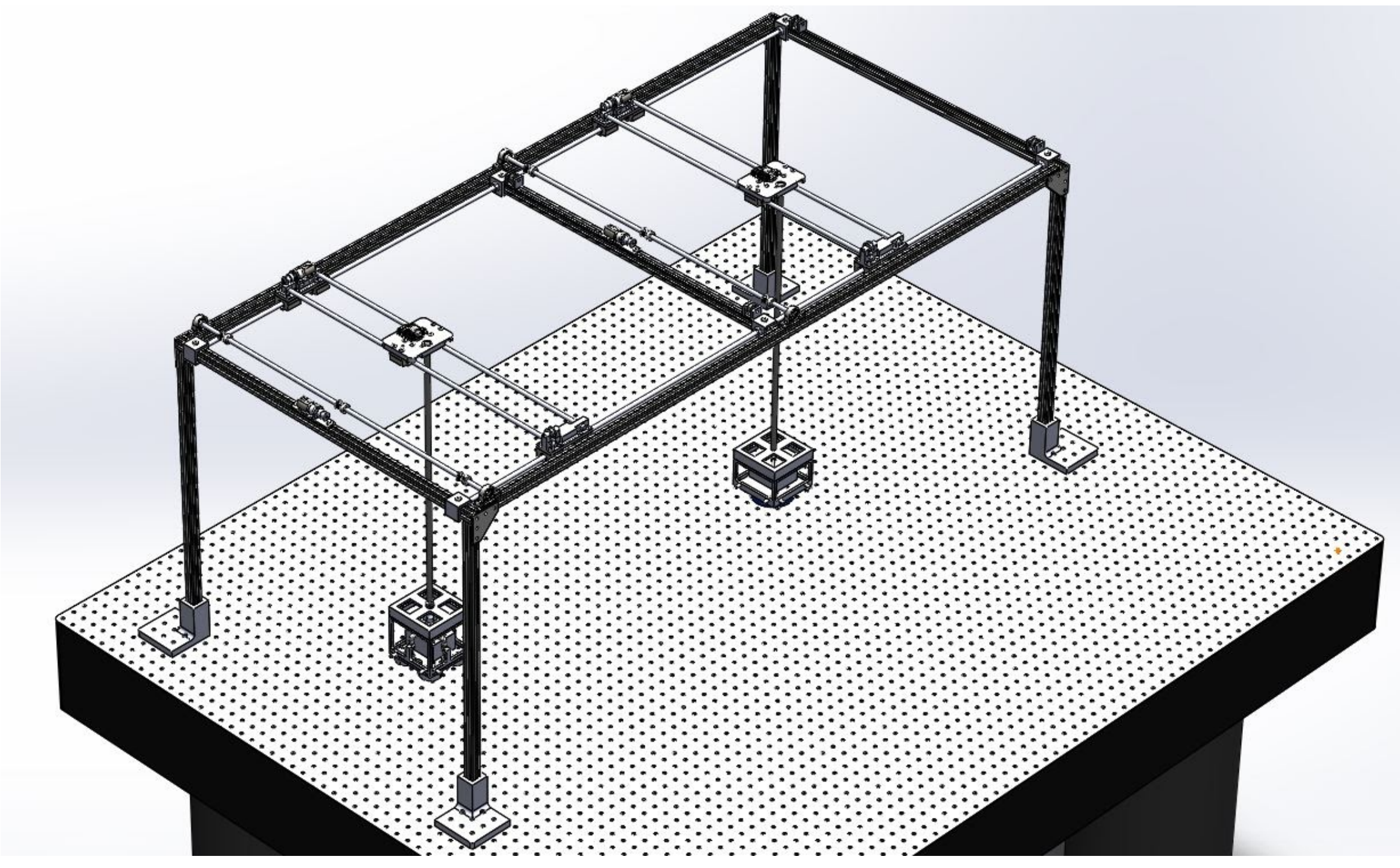

Figure 1: CAD model of the formation flight testbed showing CubeSat models levitating on the optical table, and the Overhead Hose Carrying System.

Motion System

In order to provide the 2D planar motion required for the air hose to follow each cube, a dual axis drive system was created using DC motors, timing belts and pulleys, linear guide rods, and linear bearings (See Figure 4 for labeled diagram). The stationary motor (1) uses a short timing belt (10) to turn a drive shaft (5). This drive shaft then simultaneously turns two pulleys (3, 4) which along with attached timing belts (7, 9) translates the entire hose-trolley section (6) in the x-axis. This section, which slides along guide rods (11, 12), uses a second motor (2) and a timing belt (8) to create y-axis motion of the hose-trolley (13).

To achieve control of the hose for more than one CubeSat model, this motion system “square” can simply be attached side-by-side with an identical motion system “square.” The OHCS design uses two adjacent motion systems, allowing control of two hoses and thus two CubeSats. Because of the modular nature of the design, the OHCS can be easily scaled up to accommodate more CubeSat models if desired.

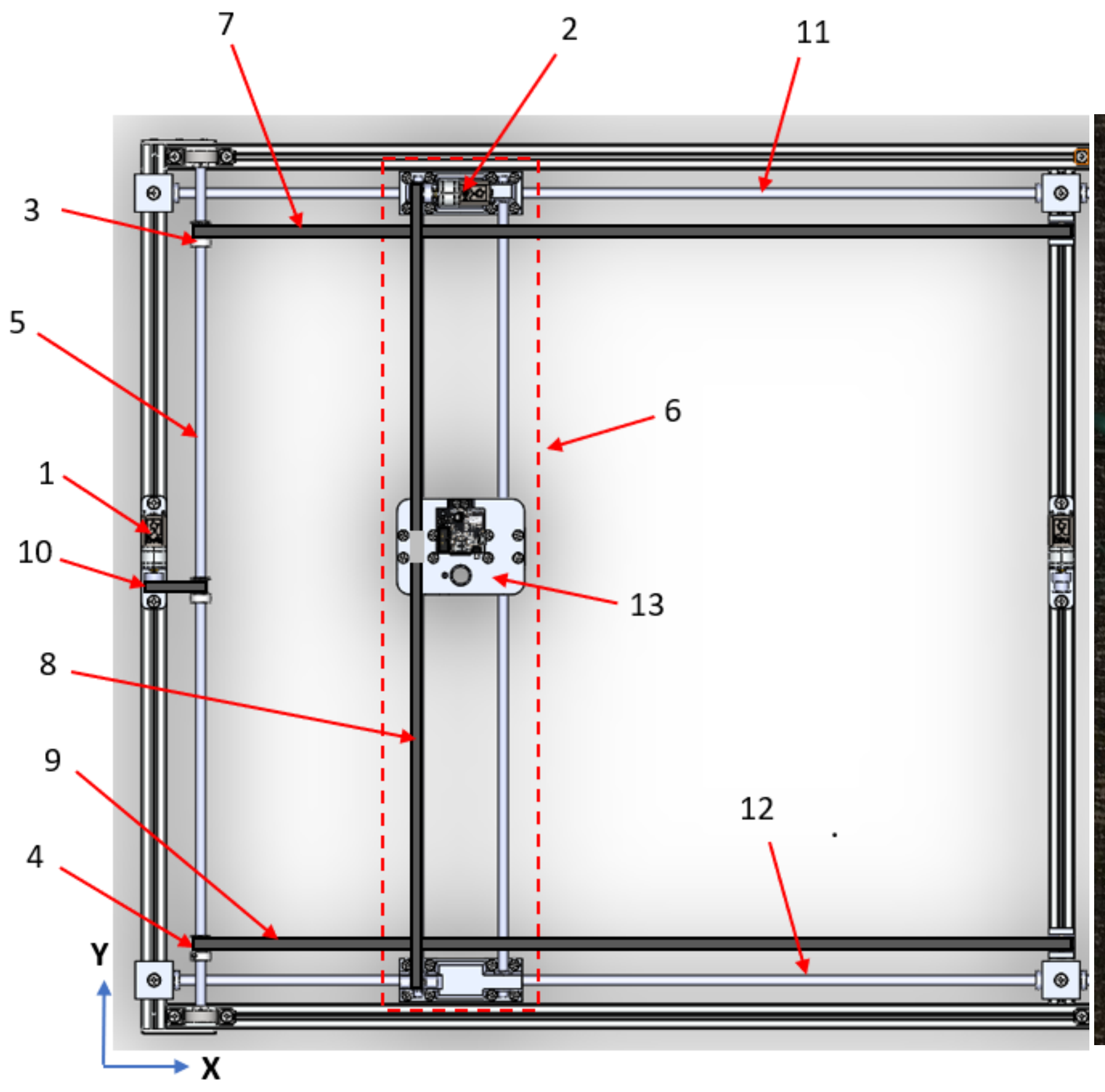

Figure 4: Labeled overhead diagram of an OHCS modular section.

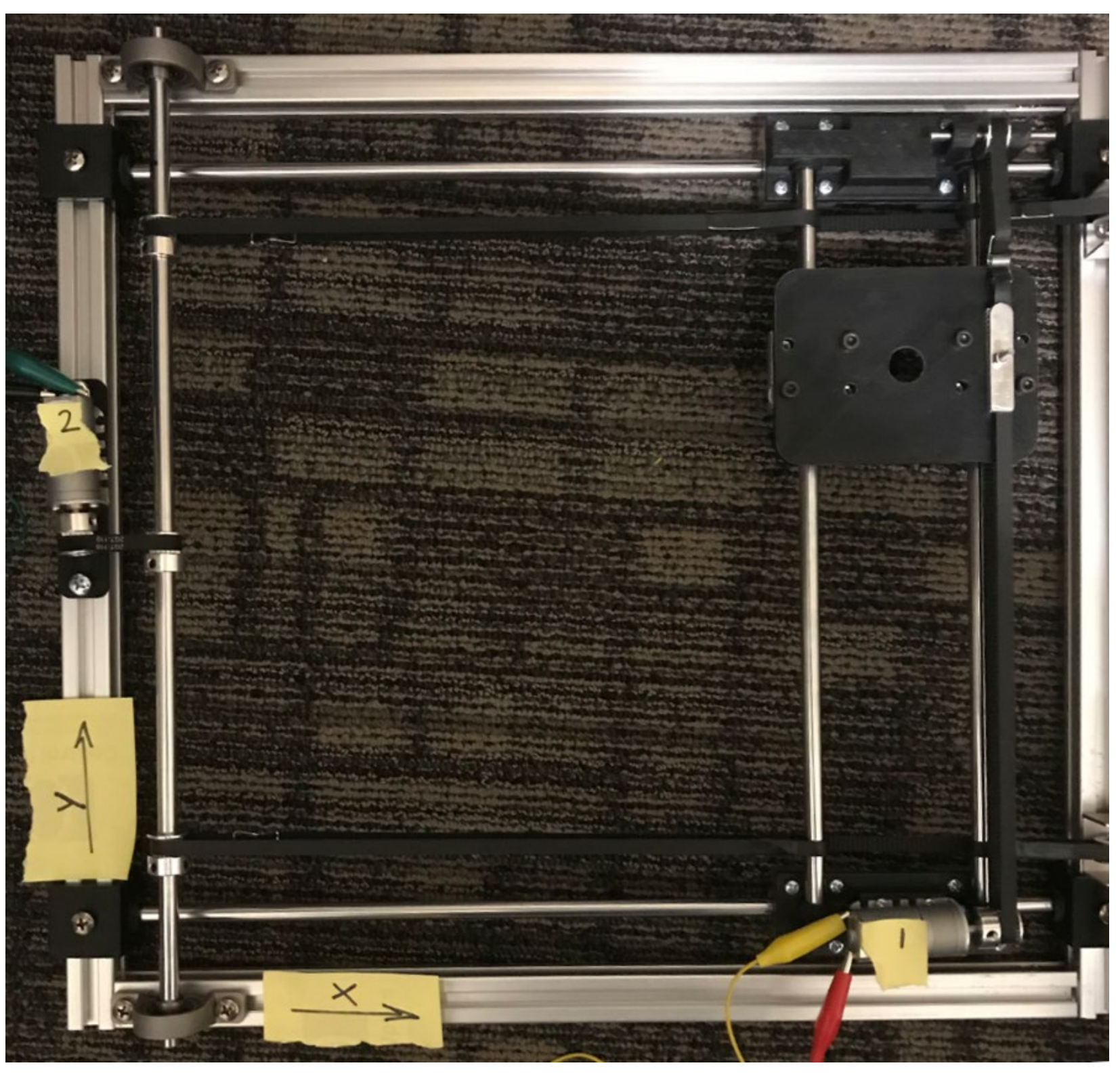

Figure 5: Prototype scaled-down build of OHCS modular section.

Considerations

- Cheap to manufacture (must fall within allotted funding)
- Must provide 20”x20” space for each CubeSat to move around
- Modular design which can be easily iterated upon, even once built
- Must not interfere with motion-tracking cameras used for formation flight tests

Materials

The frame of the Overhead Hose Carrying System (OHCS) is made from T-slot aluminum extrusions. T-slot is a type of cheap yet relatively stiff extrusion that allows for modular mounting of nearly endless items to the rail. By taking advantage of the unique shape of the rail, a specially shaped nut and small screw are all that’s needed to attach any item to the rail. By creating the frame out of T-slot, the motor mounts, bearings, and other items used in the design can be easily attached or removed from the frame or moved somewhere else on the frame.

Figure 2: Illustrations of t-slot aluminum extrusion and its cross-section.

Many other parts, such as the motor mount, guide rod holders, and sensor trolley utilize 3D printing to create cheap, iterable, and fully custom components without the need for machining. This 3D printing approach allowed designs to be printed and tested right away, then reworked as necessary.

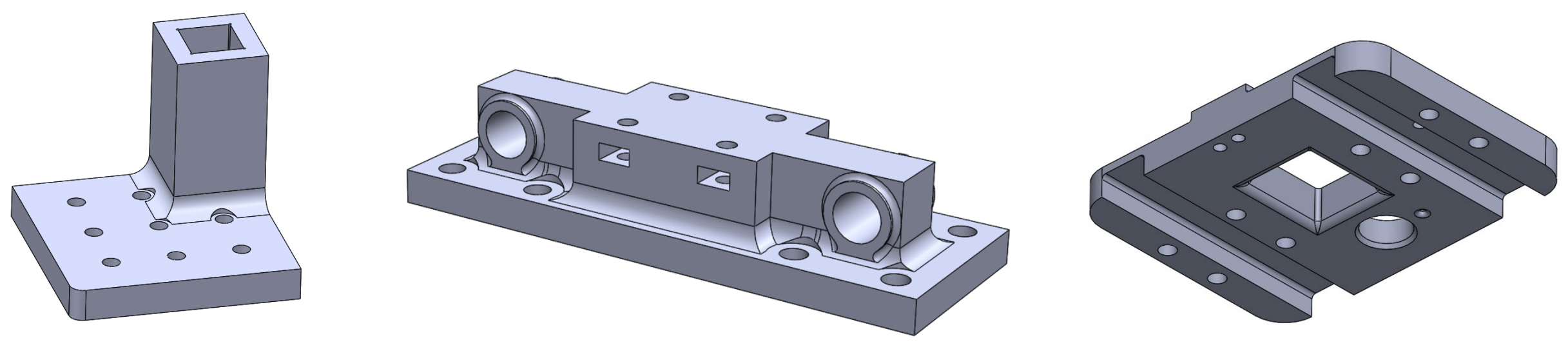

Figure 3: CAD models of some of the parts that were 3D printed. Left: Mounting foot. Center: Motor mount/guide rod holder. Right: Motion tracking camera mount/bearing mount.

X-axis motion considerations

The choice to use a drive shaft (labeled ‘5’ in Figure 4) to create X-axis motion may initially seem odd, as it would be simpler to directly drive one X-axis belt with a single motor as shown in Figure 6 or use a motor to drive each of two X-axis belts. The idea to use two motors, one driving each X-axis belt, was eliminated because it would be difficult to precisely sink the movement of these two motors, potentially causing the X-axis to bind if one motor turned faster or slower than the other. In addition, adding an extra motor would drive up the cost of both motors and motor controllers. So why not just directly drive one of the X-axis belts with a single motor? This comes down to whether the bearings will seize in this configuration and can be determined by a bearing stick-slip calculation (see section below).

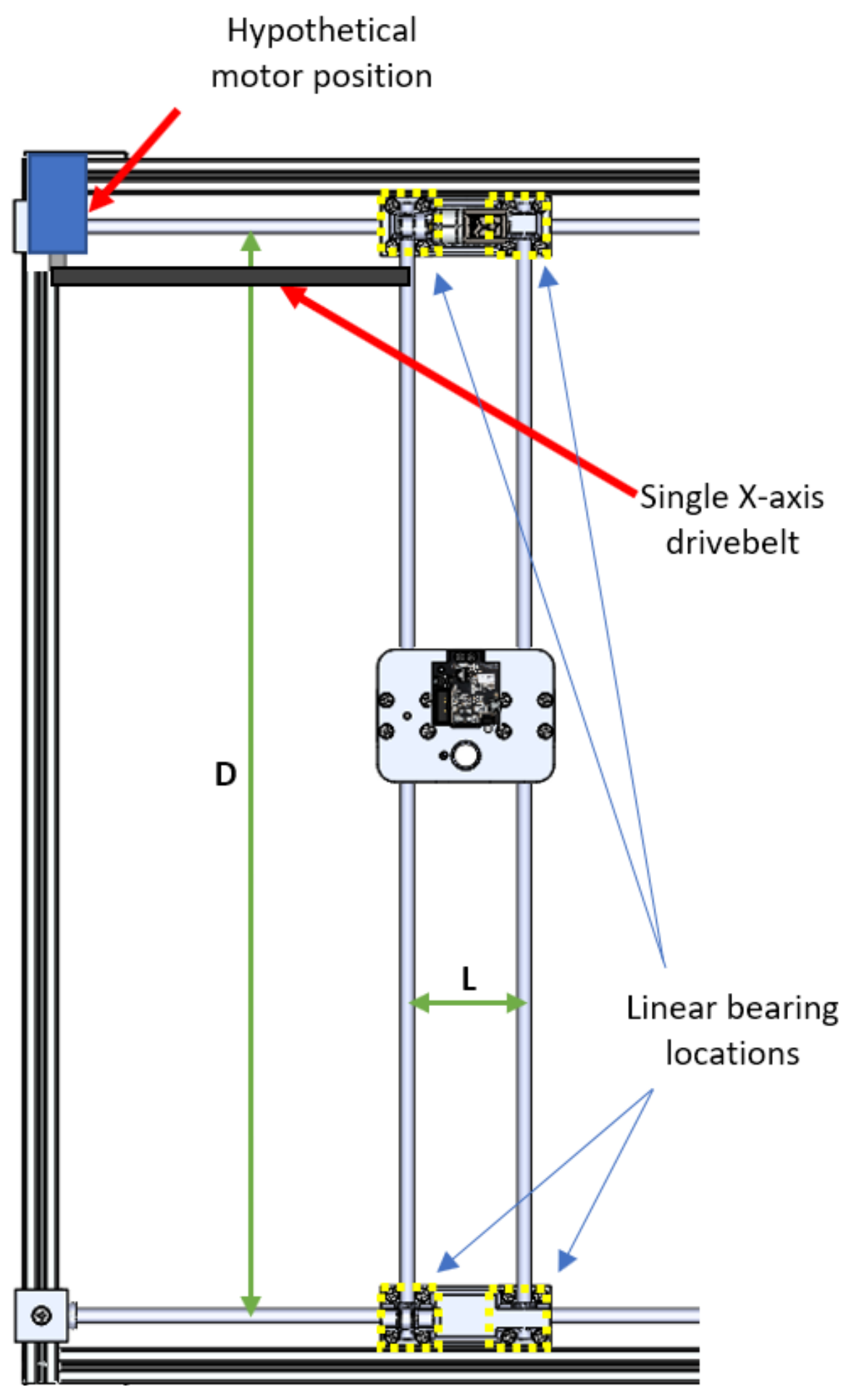

Figure 6: Hypothetical single-drive X-axis motor and belt.

Bearing stick slip calculation

Objective: Determine if bearings will seize and prevent X-axis motion if one drive belt is directly driven by a single motor.

Using statics principles, the following equation can be derived:

$$\mu < \frac{L}{2D}$$

where μ is the static friction coefficient between the linear bearing and guide rod, and L and D are the dimensions labeled on Figure 6.

For the desired L and D, μ must be less than 0.076.

The actual μ was determined experimentally and was found to fall between 0.06 and 0.11.

Conclusion: Unless a best-case scenario is assumed with little margin for error, the friction between the bearings and the guide rods is too high to allow movement in this configuration. Thus, a driveshaft solution must be used to move two belts simultaneously.