Development of Hardware and Actuator Components for Modular Tetrahedral Truss Robots

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***Abstract*—A modular robot connects a group of unit cells to create a moving robotic system. These robots often utilize the tetrahedral shape as a unit cell because of its ideal geometric abilities to distribute tension and stress isotopically. Recently, modular tetrahedron robotics actuate using variable geometry truss (VGT) or variable topology truss (VTT) that manipulate the edge length and topology of the tetrahedron unit cells but often experience actuation issues. Origami robotics address these limitations by using compliant joints to simulate similar movements achieved by VGT and VTT as well as bypass the actuation issues. Therefore, this proposal aims to explore origami robotics as a suitable alternative for VGT and VGT actuation. First, we aim to modify the *Trussbot,* a tetrahedron origami robot, to address the movement limitations that the *Trussbot* encountered in its prototype. The challenge is to create custom mounts for electronic components, designate wiring to avoid tangling, and manipulate a control board and pins that should enable the *Trussbot* to execute its movements more fluidly. To fix the electronic components to the robot, three-dimensional modeling and printing to find the best combination of dimensions and slicing for the mounts. A miniature breakout board was formalized using adobe illustrator and materialized via PCB circuit board, solder, and insulated wire. Second, we use the tetrahedron unit cell modules to explore a two-degree of freedom robotic arm option. The experiments and modifications explore the exciting possibilities of using tetrahedron unit cells in the ever-growing field of origami-modular robotics.**

***Index Terms*— Modular robot, tetrahedral, origami robotics**

I. INTRODUCTION

Modular robotics connect multiple unit structures into a singular robotic system that can be actuated through electronic components [1]. The tetrahedral shape's ideal geometric properties and ability to distribute stress and tension throughout its six edges and four vertices boost its use as a unit module in modular robots [2]. Recently, research involving tetrahedral robots use variable geometry truss (VGT), which manipulates the length of the tetrahedral edges [2,3,8], and variable topology truss (VTT), which changes the configuration of the tetrahedrons [4], to actuate tetrahedral robots. For instance, locomotive robots [5,6], robotic arms [7,8], and construction vehicles use the VGT and VTT techniques to perform the same actions as traditionally manufactured robots but with the added geometric benefits of the tetrahedral shape. However, these newer techniques are sometimes coupled with actuation difficulties [7].

Therefore, our goal is to utilize static tetrahedral trusses and origami methodology to create compliant robotic systems. Our proposed robots use four-bar linkages and compliant joints via rubber bands to complete specific twisting patterns that mobilize the robots. While the VGT and VTT allow for flexibility of a robotic system, implementing compliant joints achieves a similar task. Previously, a prototype of the *Trussbot,* a climbing modular robot, used this technique to actuate a locomotion pattern based on pinching four-bar linkages together [9]. To further its development we must create custom mounts for electronic components to attach to the *Trussbot,* designate wiring to avoid tangling, and manipulate a control board to enable the *Trussbot* to execute its specific movements. Secondly, we aim to design and actuate a two-degree of freedom (DoF) modular robotic arm using tetrahedral trusses as well. Our goal is to use 3D modeling and electronics to address at the tetrahedral robotic systems limitations in actuation.

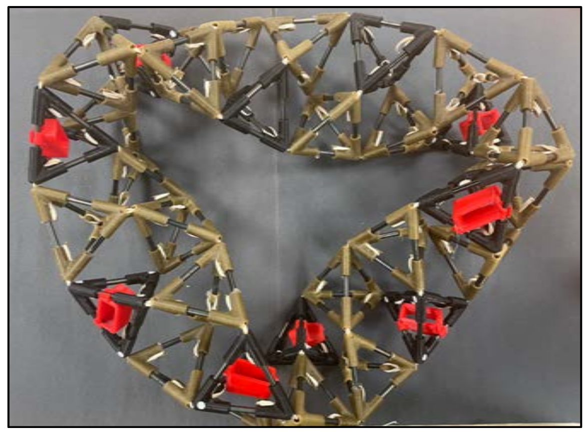

Figure 1: The *Trussbot,* a tetrahedron origami based- modular robotic system, uses thirty-one unit cells tetrahedron and connects them via compliant joints to initiate continuous movements once actuated.

II. BACKGROUND

Recently, computer analysis programming [10], modular folding robots [11], and self-reconfigurable robotics [12] utilize compliant joints to better actuate modular robots and complete specific tasks. These compliant joints are used to allow flexibility and mimic the strategic folding involved in origami. This process results in robots optimizing movement possibilities with multiple configurations and applications.

The *Trussbot* is a modular origami-inspired robot composed of thirty-one tetrahedral trusses connected in a circular shape by their compliant joints [9]. The *Trussbot* operates by pinching certain tetrahedral together in a pattern that allows the robot to twist continuously. While other climbing robots often use wheels or grasping arms, the *Trussbot* simplifies assembly and actuation by using origami and geometric concepts to create a robot that can climb and move by completing rotation cycles. The finite element analysis simulations of the *Trussbot* successfully executed the movement pattern by modeling springs between the tetrahedrons. However, the physical prototype demonstrates the movement pattern by manipulating the distance between tetrahedral components using spools of wire controlled by motors. It experienced difficulties climbing and rotating due to intricate wiring, oversized electronic components, difficulties with spool size, and heavy compliant joints. These limitations will later be addressed in this paper.

Tetrahedral truss geometry is also used in the creation of modular robotic arms [7,8]. In previous research, one DoF robotic arms are actuated using VGT and electronic components. Therefore, variable edge lengths are manipulated to move the truss arm resulting in each truss module having varying degrees of freedom. Modular robotic arms that are actuated in this fashion often experience difficulties in control or actuation.

In this project, we created electronics mounts, breakout boards, and more tetrahedral components to better build and actuate the *Trussbot* and the proposed two degree of freedom robotic arm. The developments in this project will be used towards exploring the field of origami tetrahedral truss robotics to be a suitable alternative to VGT and VTT actuation.

III. Mechanical and Electronic Components

The *Trussbot* is made of thirty-one tetrahedral units connected by compliant joints in a helical shape. Each tetrahedral unit cell has four, three-dimensionally printed vertices connected by six steel slot spring pins (figure 4). These tetrahedral components are printed separately to better allow the isotropic distribution of tension and stress. Furthermore, different tetrahedral units in the *Trussbot* will store the batteries, microcontroller, and breakout board. Three-dimensional mounts will attach these electronic components into the tetrahedral units and will also enable easy removal and modification of the electronics.

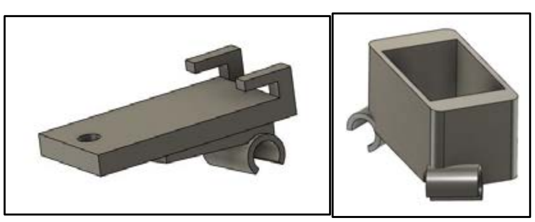

Figure 2: The leftmost mount can fix the microcontroller and breakout board to the tetrahedron unit cell. The battery mount can fix two batteries into the tetrahedron.

Computer programs streamlined the production of electronic component mounts and the breakout board. The Autodesk Fusion 360 program aided in the creation of three-dimensional battery and microcontroller mount models. Afterward, the Original Prusa Mini 3D Printer printed these models and vertices for the robotic arm tetrahedral unit cells. Adobe illustrator helped in illustrating the connections and pathways for the breakout board.

A. *Microcontroller and Battery Mounts*

The electronic mount clips onto the steel spring edges of the tetrahedral units and fix the electronic components inside the tetrahedral. One challenge was ensuring the mount and electronic component fit comfortably inside the tetrahedral so that the tetrahedron unit cells pinching movement is enabled. The Teensy 3.2 microcontroller mount clips around the silver port in the middle of its top edge (figure 4). We experimented with multiple iterations of the

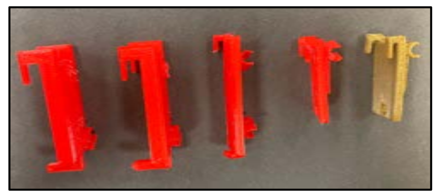

Figure 3: Printing the mounts in this orientation, on its side, was best. Multiple iterations of the breakout board were printed using varying dimensions and slicing processes.

microcontroller mount to optimize its dimensions and 3D printing procedures (figure 3). The first proposed model fixed the microcontroller into the side of the tetrahedral but prohibited the wires that connect the motors to the microcontroller. A second model addressed these limitations by securing the microcontroller into the middle of the tetrahedral (figure 4). Printing a mount on its side, (figure 3), and applying supports between the clips and within the grasper worked best in achieving the miniature details correctly. Initially, the MakerGear 3D printer posed problems in printing the mounts and graspers in one piece. Therefore, using the Original Prusa Mini printer proved to be a better option because of its tunable support capabilities.

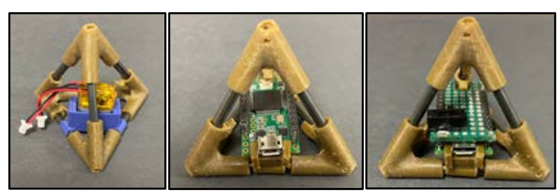

Figure 4: The blue battery mount and brown breakout board connect to the steel springs. These steel springs act as edges between the brown vertices. The middle image shows the Teensy 3.2 breakout board which is 1.4x0.7x0.07in.

The battery mount was more straightforward as its options to fix two 3.7v batteries inside the tetrahedral were more limited. The first model consisted of two graspers and a casing to set the batteries inside. However, the casing height in this model produced issues in removing the batteries. Therefore, the second model shortened the casing around the batteries and added a slot on the bottom of the case to provide two options for retrieving the batteries. While 3D printing the vertices and mounts are the best options for prototyping, in the future, the tetrahedral vertices and electronic mounts could use other printing techniques to produce the objects in bulk.

B. *Breakout Board*

The *Trussbot* uses 10 Servo Motors that each requires a digital, analog, ground, and voltage pin. The Teensy 3.2 Microcontroller board is ideal for the *Trussbo*t because of its small size and available digital pins (10) and analog pins(10). However, the Teensy breakout board only has 1 ground and 1 voltage pin. Therefore, to create more available ground and voltage pins we create a breakout board (figure 5). A breakout board creates a customizable electrical circuit that's similar to a breadboard and extends the microcontroller. The challenge was creating a breakout board that could easily fit into the tetrahedron model and preferably on top of the microcontroller. The breakout board also needed to encompass room for a three-pronged switch and ports for the battery to connect to the *Trussbot*. A suitable circuit pattern that met these requirements was developed and illustrated using Adobe Illustrator. Later,

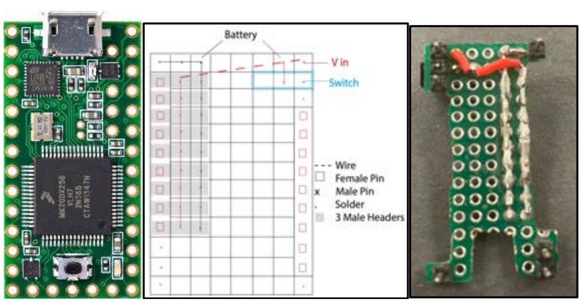

Figure 5: The breakout board will attach directly to the Teensy 3.2 microcontroller (leftmost picture). Before creating the physical breakout board (rightmost), a plan was cultivated using Adobe illustrator.

the proposed board was created by cutting a PCB board to the microcontroller size and soldering the proposed connections using insulated wire and rosin core solder. Additionally, male headers are placed in the corners to plug into the microcontroller board and act as supports.

C. *Three-Dimensional Arm*

We printed seventy-two tetrahedron vertices, filed the supports down, and connected them with steel springs to create the tetrahedron unit cells. Afterward, the unit cells were arranged to explore the tetrahedron truss two degrees of freedom robotic arm. The arm arrangement is a series of four-bar linkages similar to the *Trussbot.* The first possible configuration utilizes a grasper connected to a motion base. The model would use five four-bar linkages (figure__) to grasp objects while another five four-bar linkages used to steer the arm. The second configuration would connect all ten four-bar linkages in a long chain and snake around items to grasp them.

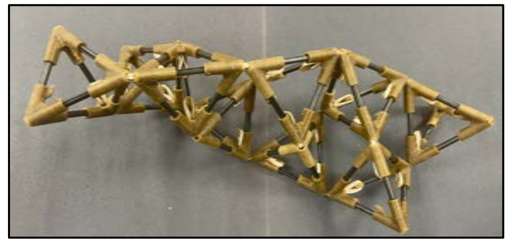
Figure 6: The tetrahedron unit cells are arranged in four bar linkages to best grasp objects and control its movement.

IV. Discussion and Conclusion

The *Trussbo*t modifications and robot arm development further the exploration of compliant joint modular tetrahedral robotics. The completed breakout board, microcontroller mount, and battery mount allow these robots to complete specific twisting without their previous limitations.

Future work on the *Trussbot* includes testing the robot's ability to climb a 6.48" diameter pole horizontally and vertically. We will place the servo motors into the black tetrahedral and actuate the pinching movement by uploading tailored Audrino code. We will observe the rotational speed for each locomotion cycle performing horizontally or vertically.

The robotic arm experimentations will examine its motion range and grasp on objects. We will test the two different configurations explained previously. The long-chain robotic arm configuration will have motors placed identically to the *Trussbot* servo motor placement. The grasper and short arm configuration will have a different motor placement. We would attach the motor into the middle of the grasper portion and two in the small arm spaced equidistant from the middle. We will actuate these robotic arms with customized Audrino code. We plan to observe their ability to grasp objects with varying dimensions and textures. Finally, another possibility is to add tactile sensors to both of these robots to initiate specific movements.

V. Acknowledgments

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