ICRA2026 Late Breaking Results Poster presented at
2026 IEEE International Conference on Robotics and Automation (ICRA 2026)
June 1-5, 2026. Vienna, Austria

Design and Development of a Spiral Chain Actuator*

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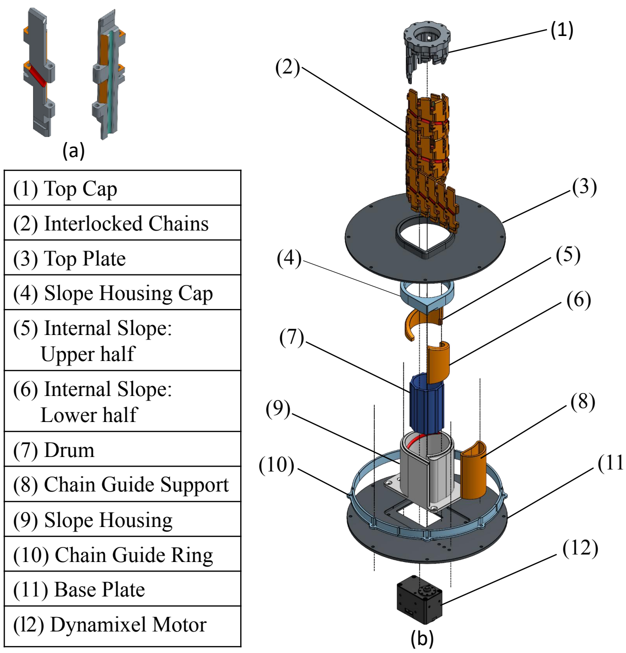
***Abstract*— In this paper, design and experimental validation of a novel Spiral Chain Actuator and its application in a three-degree-of-freedom positioning platform are presented. Unlike previous spiral zipper actuators that rely on flexible bands and face structural integrity limitations under tensions and moment loads, the proposed design employs rigid chain pieces that interlock during rotation. This rigid architecture enables an improved load-bearing capacity while maintaining the compact, lightweight advantages of spiral actuation. We developed a positioning platform equipped with three Spiral Chain Actuators arranged in a tetrahedral configuration and validated position control through experimental testing. The results demonstrated successful position tracking across all three translational axes, which establishes foundation to develop full VTT system and it's performance evaluation in the future.**

I. INTRODUCTION

A Variable Geometry Truss (VGT) system consists of truss members connected by spherical joints and is capable of changing its member lengths to control its geometry [1]. Linear actuators are commonly used as members in this system [2]. Early concepts proposed the Trussarm as a VGT manipulator arm [3]. The Variable Topology Truss (VTT) system expands on VGT systems and differs in its ability to reconfigure by splitting and merging nodes, allowing it to form different topologies depending on the operational scenarios [4], [5]. The system controls the lengths of the members while simultaneously altering its topology [6]. VTT systems must consist of active linearly actuated prismatic members to support reconfiguration and must maintain structural rigidity through rigid components [7].

Collins and Yim presented a spherical robot arm featuring a spiral zipper prismatic joint, which was strong in compression but showed looseness under tensile and moment loads [8]. The design evolved from earlier concepts including Lifting Jack [9] and more recent applications such as Zippermast [10] and Spiralift [11]. The Spiral Zipper uses a flexible plastic band design that forms a rigid column during rotation through a tooth interlocking process. However, this flexible band design imposes limits on structural integrity. Maximum band length constraints exist where longer bands result in tension and moment limitations [8].



(1) Top Cap
(2) Interlocked Chains
(3) Top Plate
(4) Slope Housing Cap
(5) Internal Slope: Upper half
(6) Internal Slope: Lower half
(7) Drum
(8) Chain Guide Support
(9) Slope Housing
(10) Chain Guide Ring
(11) Base Plate
(l2) Dynamixel Motor

Fig. 1: (a) Front and Back isometric view of chain design (b) Exploded view of the full Chain Actuator design with it's components

The Spiral Chain Actuator addresses these structural limitations by employing rigid interlocking chain pieces. This design maintains the compact spiral actuation principle while improving tension and moment resistance, which are critical requirements for VTT systems. Each chain piece mechanically interlocks with adjacent pieces during rotation, forming a rigid column that supports tensile loads directly. In addition, this work implements the ROS2-based control architecture with inverse kinematic approach, along with experimental validation of position control with three actuators.

II. THE SPIRAL CHAIN ACTUATOR

A. Hardware Design

Fig. 1(a) shows isometric view of single chain design and (b) presents detailed design of the spiral chain actuator with it's different elements. It's six primary components include top cap, interlocked chains, internal guide slopes, drum, base plates and Dynamixel motor. Each actuator currently provides 54 mm of linear extension per full revolution. The actuator length can be adjusted by adding or removing rigid chain pieces. Alignment is achieved through the interaction between the drum teeth and a continuous groove in each segment. Internal slopes further regulate motion, enabling smooth transition from storage to deployment while the housing guides and constrains chain motion.

Fig. 2(a) shows front and back view of 3D printed chain pieces. To reliably maintain this intended geometry, each

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*This work was not supported by any organization. (*corresponding author: A. Bae*) (*co-first authors: R. Subedi, S. Gourdet and L. Harris*)

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chain piece integrates three key geometric features: a travel-distance limit that raises each segment to a consistent height during extraction, an inward bending-angle restriction that preserves the polygonal profile, and a mechanical interlocking interface that prevents vertical separation between adjacent segments. Structural continuity is achieved through an interlocking mechanism, where the top groove of each segment engages with the bottom protrusion of the next segment. This rigid interlocking enables direct load transfer, improving load capacity compared to flexible designs. One full cycle of the actuator consists of ten chain pieces.

B. Control Structure

The positioning platform as shown in Fig. 2(b) is controlled using ROS 2 based controlled architecture that implements both forward and inverse kinematics control strategies. The setup includes a Raspberry Pi, Dynamixel U2D2 interface, Power Hub Board, and Dynamixel SDK. Raspberry pi runs ROS 2 control packages, Dynamixel U2D2 Interface allows for communication with the actuator, PHB provides power to motors, and Dynamixel SDK includes low level control functions along with encoder reading.

There were two methods for testing. The first method uses the position of top plate as the input for the inverse kinematics based control. The desired and current node positions are used to compute the corresponding lengths. This is followed by a proportional controller to calculate the velocities of each actuator.

The second, simpler, method uses the desired lengths as a direct input for each actuator. In this approach, the ROS2 trajectory generator publishes desired lengths on a topic, and the motor control node subscribes to these lengths, converting them into Dynamixel position commands. The position of each motor is read in encoder counts, and the number of revolutions required to reach the desired position is calculated as follows:

$$N_{rev} = \frac{L}{Z_{cm}}, \tag{1}$$

where, N_{rev} is the number of revolutions the motor needs to rotate, Z_{cm} is the linear displacement the actuator travels per revolution and L is the length of actuator.

III. PRELIMINARY TEST RESULTS

To validate the performance of the Spiral Chain Actuator, directional motion experiments in the x, y, and z directions were performed. The experiment consisted of six discrete motions, +6 cm and -10 cm in z, and +5 cm and -10 cm in both x and y directions. In the y-direction motion, actuator responses were asymmetric due to the base's T-shaped geometry, with actuators 1 and 3 behaving similarly while actuator 2 adjusted to maintain the end-effector position.

IV. DISCUSSION AND FUTURE PLAN

This paper presented the design, implementation, and experimental validation of a novel Spiral Chain Actuator using rigid interlocking chain pieces. For experimental validation, a three actuator positioning platform was developed and it's position control was achieved using ROS2. Future work following this will focus on three directions: (1) Force sensing and load characterization to quantify maximum tensile and compressive capacity, (2) Integration into a full Variable Topology Truss system to evaluate reconfiguration performance, and (3) Design optimization to reduce backlash and improve position resolution through refined structure geometry.

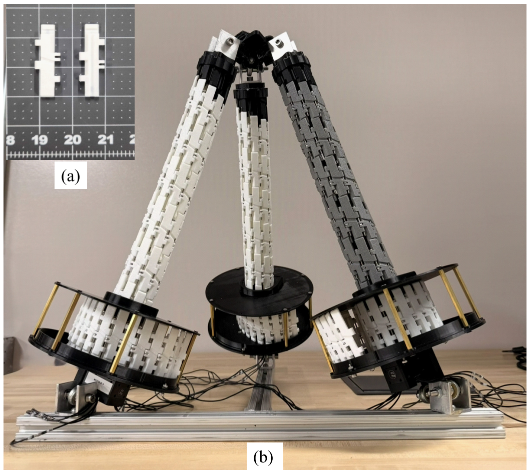

Fig. 2: Experimental setup (a) Front and back of two 3D printed chain piece (b) Full positioning platform with three Spiral Chain Actuators

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