A Novel Triad Twisted String Actuator for Controlling a Two Degrees of Freedom Joint

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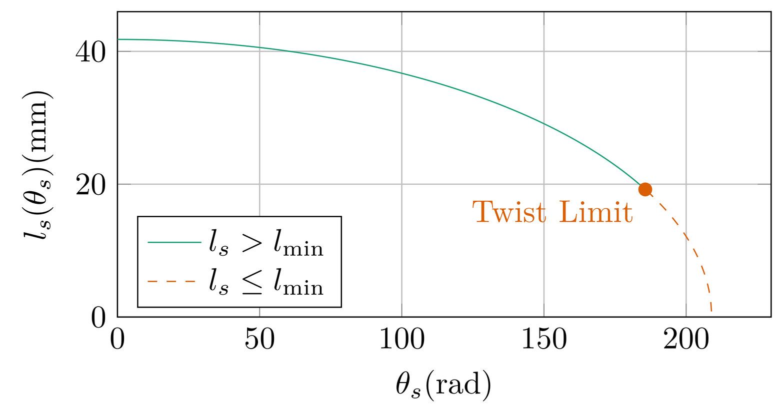
Introduction

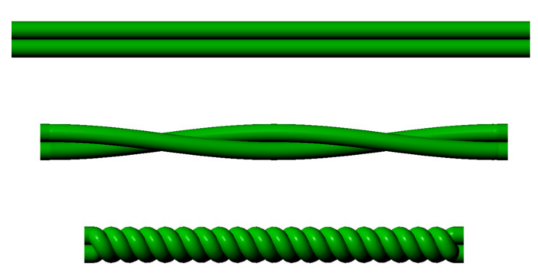
Actuated universal joints (AUJs) are found in a wide variety of robotic applications, from mobile snake robots to robotic tails. Traditionally there has been a trade-off between joint mass and overall system compactness. "Inline" actuators result in heavy segments, limiting the length of AUJ chains and end effector mass. External actuators require space outside of the robotic system to be available. This research demonstrates the use of the twisted string actuator (TSA), a light, compact actuator with a high force output, in an "antagonistic triad" configuration to actuate an AUJ.

Background

Twisted String Actuator

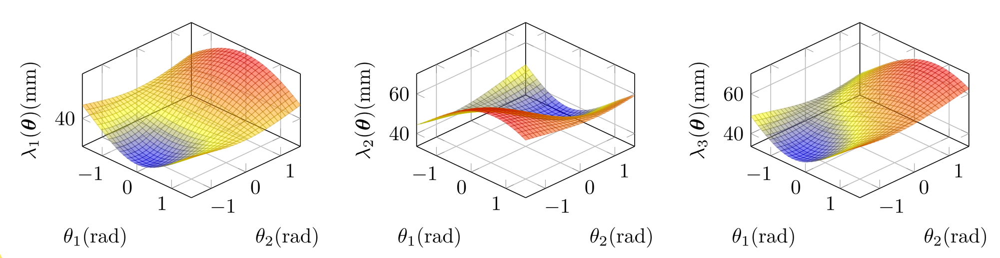
First developed by Würtz *et al.* in 2010, the TSA uses two or more strings of the same length. When these strings are twisted into an n helix, the distance between the start and end of the strings decreases, creating a linear motion.

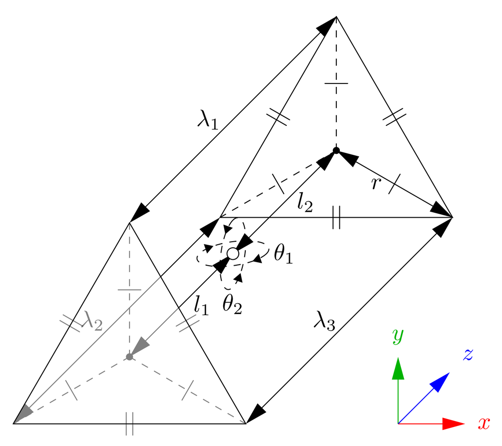




Antagonistic Triad

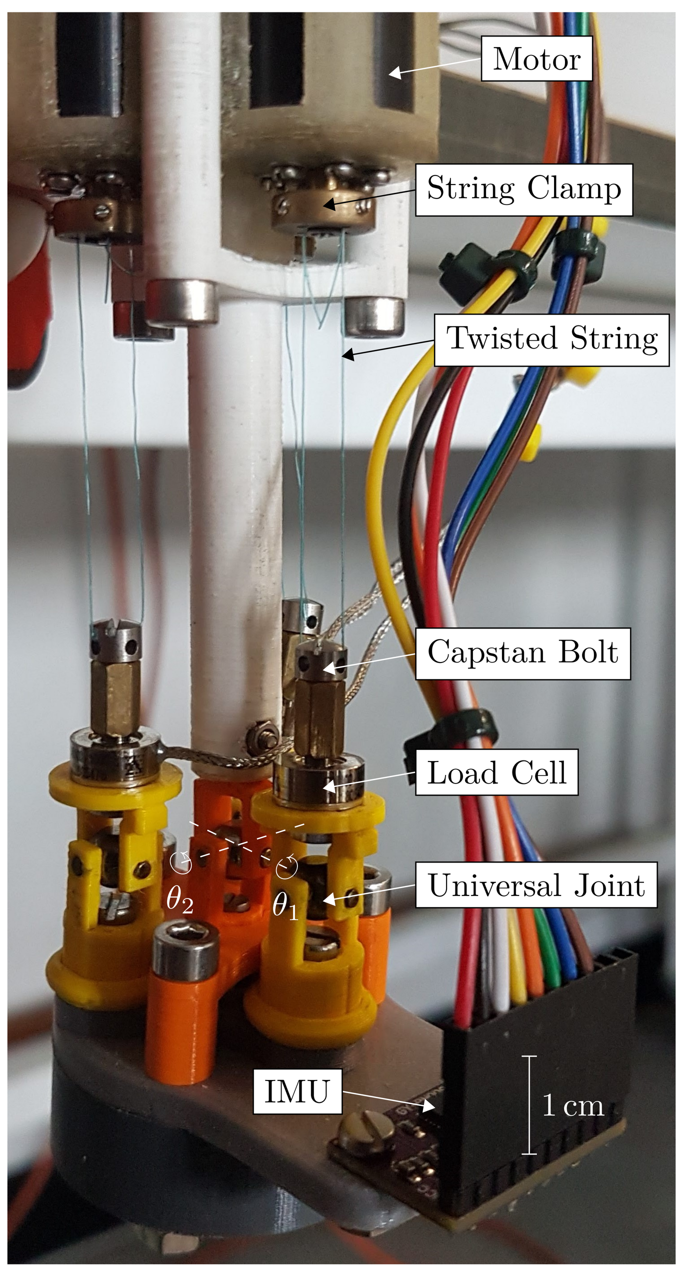
Because TSAs can only operate in tension, a minimum of 3 actuators are required to drive a AUJ in 2 degrees of freedom. This is called an "antagonistic triad" as it mimics antagonistic pairs of muscles.

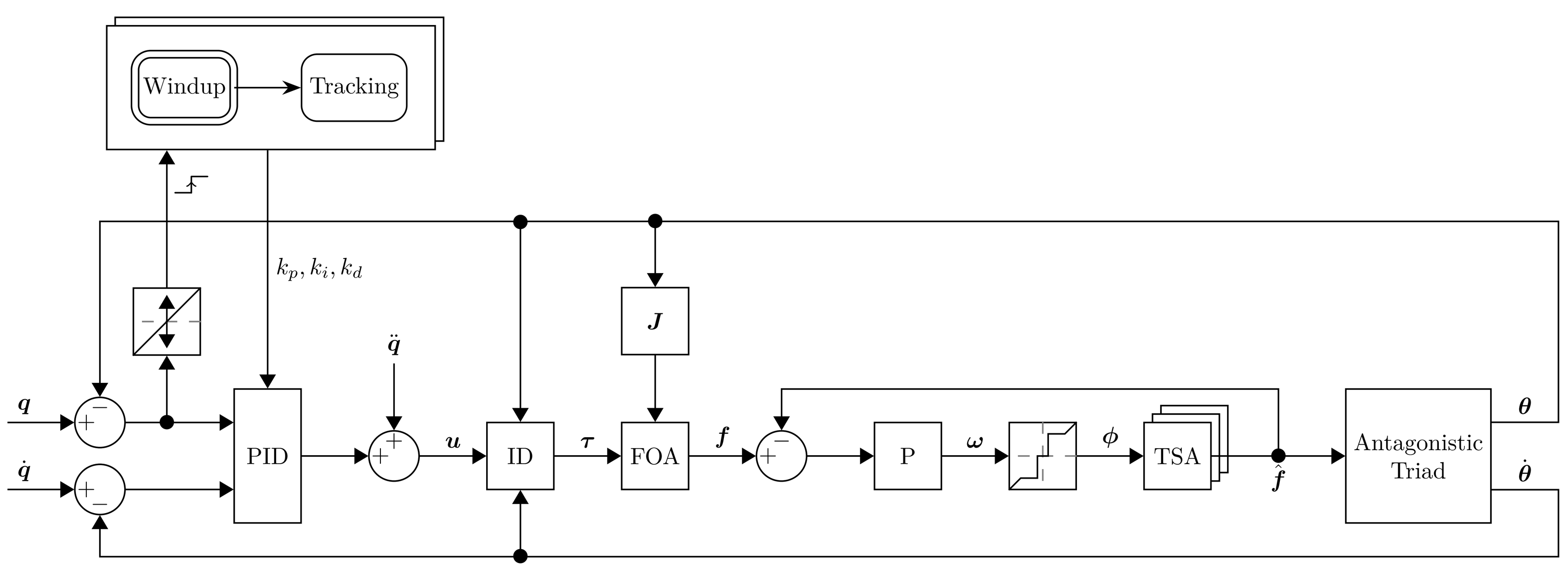




Experimental Setup

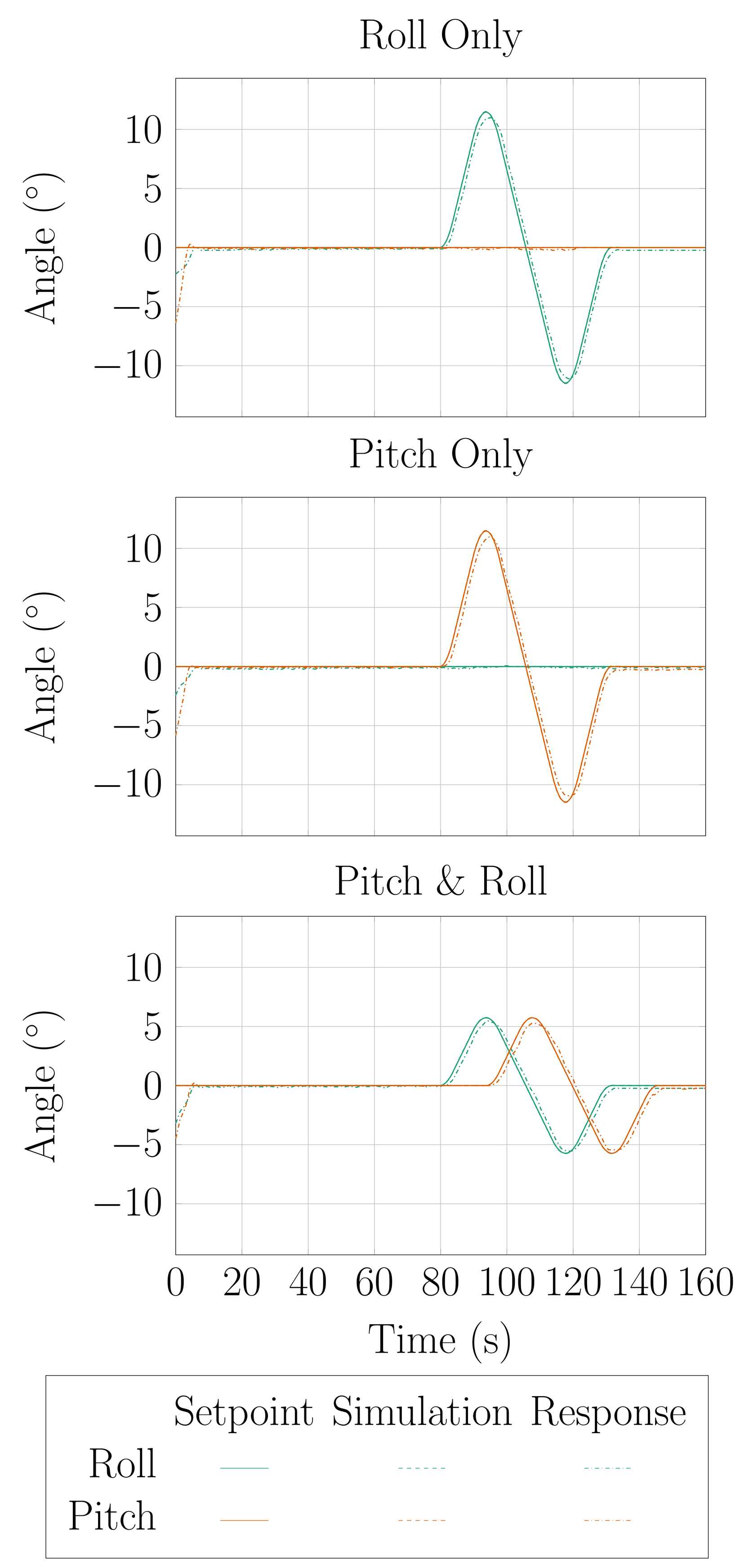
- Single segment prototype constructed in order to experimentally validate the design.
- Universal joint angular position measured using BNO080 inertial measurement unit (IMU).
- Control system consists of a four layer cascaded design which combines individual P force controllers for each TSAs using LCM100 load cells, a force controller for the AUJ from Dessen (1986), calculation of inverse dynamics, and an outer loop PD controller tracking a joint trajectory.
- Different PD values were needed during an initial "windup" stage, when the TSAs were actuating to their initial position.
- Prototype was tested with both single-axis $\pm 11°$ and dual-axes $\pm 6°$ trajectories. The small angles were used to keep string lengths short and actuator forces low for initial experiments.

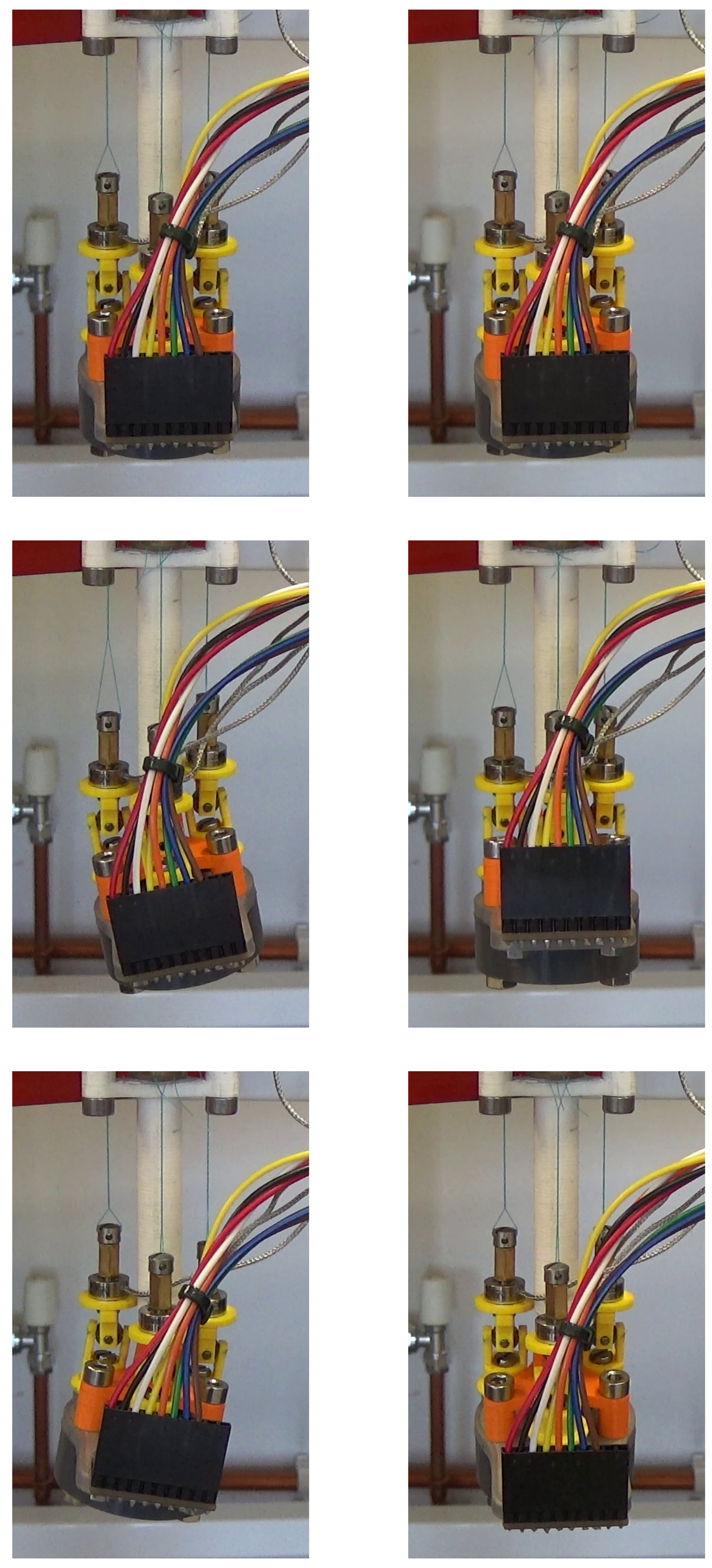




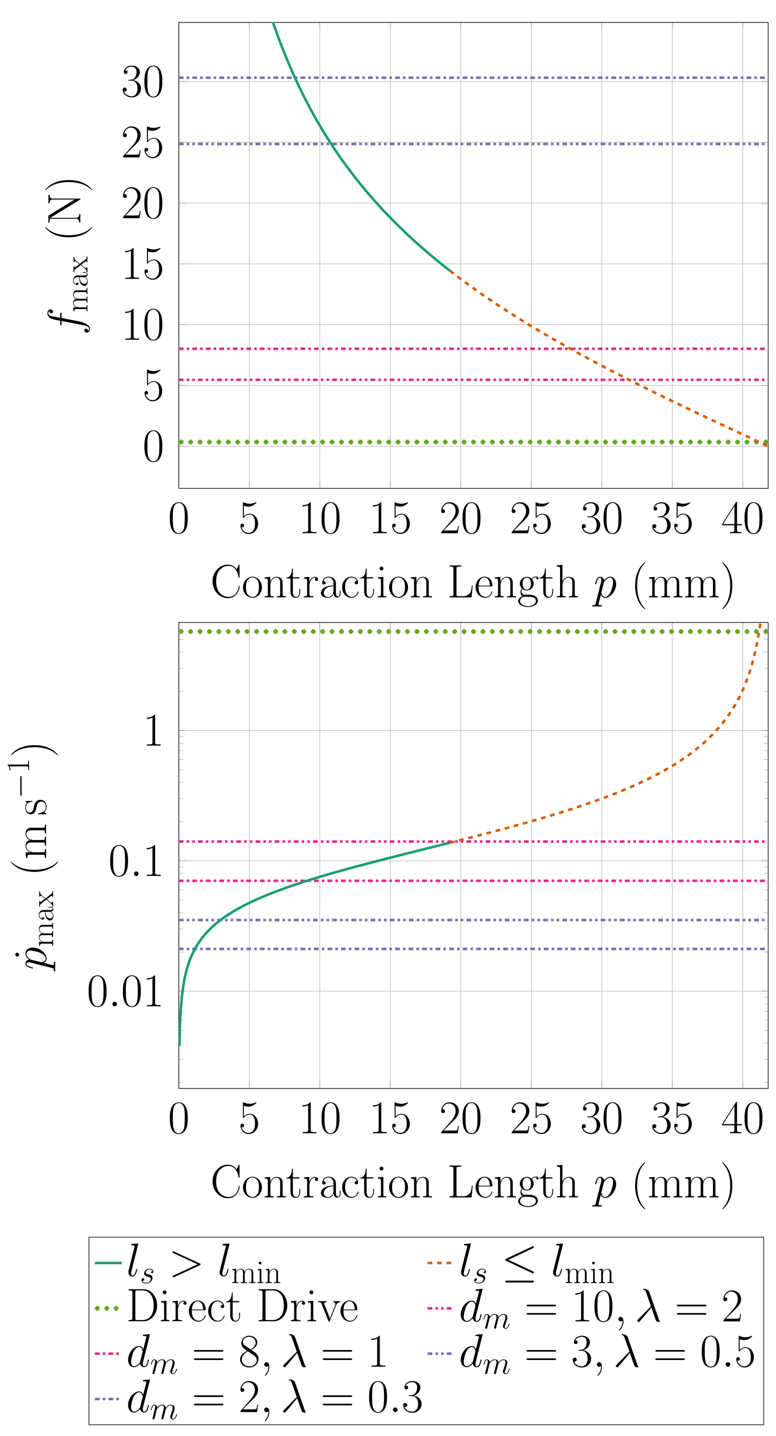
Results

Mechanism was able to track a trajectory to within $\pm 1.8°$ at max. $0.6\,°\,\mathrm{s}^{-1}$. Future experiments will aim to increase the range and angular velocity.





Performance Comparsion



- This research also compared the TSA maximum force $f_{\max}$ and maximum stroke velocity $\dot{p}_{\max}$ with two equivalent actuation methods, leadscrews of various pitches λ and diameters d_m, and the equivalent of a rotary direct drive, both using the same motor as the TSA.
- The TSA $f_{\max}$ and $\dot{p}_{\max}$ are dependant on stroke position p in a non-linear fashion, with $f_{\max}$ decreasing and $\dot{p}_{\max}$ increasing as p increases.
- The direct drive has the highest $\dot{p}_{\max}$ but the lowest $f_{\max}$.
- Depending on the values of λ and d_m, the leadscrew has different $f_{\max}$ and $\dot{p}_{\max}$. $f_{\max}$ increased and $\dot{p}_{\max}$ decreased as λ and d_m decreased.
- Both the direct drive and the leadscrew are bidirectional, so only two actuators would be needed. However, gearboxes would likely be required, increasing segment mass, potentially more than an extra actuator.

Conclusions

- Robust control has been achieved for this mechanism, which is able to accurately track a trajectory in single and dual axes.
- Further research is required to improve the range and angular velocity of the mechanism, as well as investigating its performance under increased follower mass.

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