JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING

Autonomous Suture Tension Management Device

Computer Integrated Surgery II
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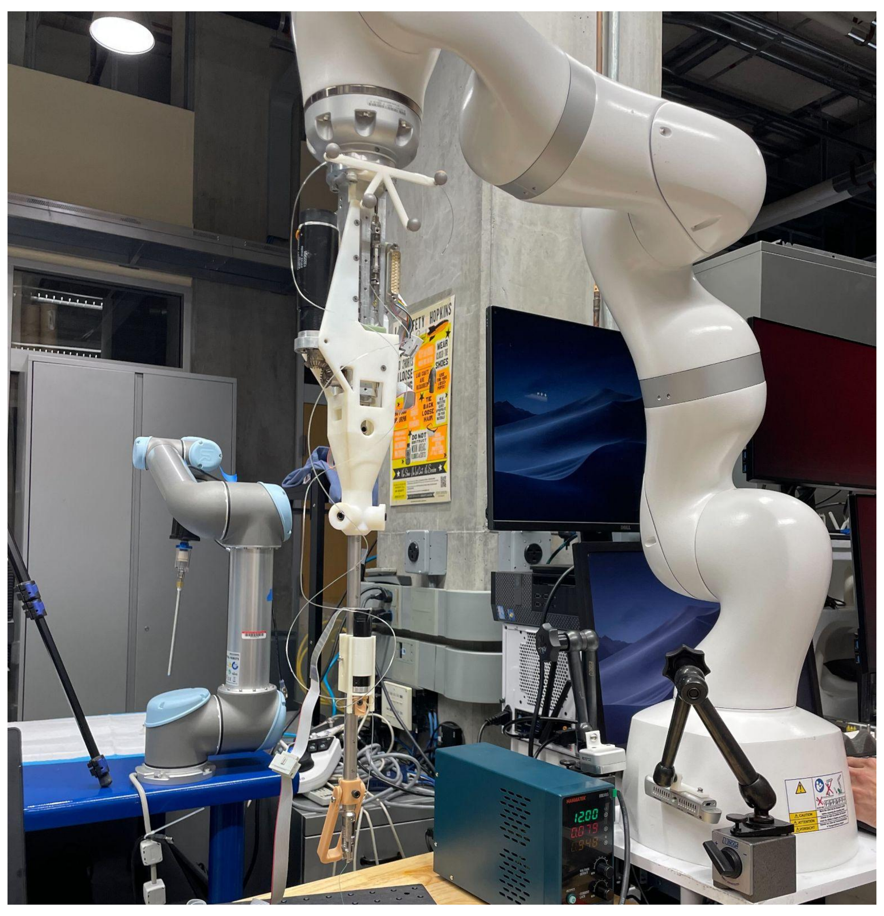
Mentors: Michael Kam and Dr. Axel Krieger

Introduction

We developed a device which attaches to the end effector of the Smart Tissue Autonomous Robot (STAR) and allows for autonomous suture tensioning management. This design could be used for fully autonomous suturing within a laparoscopic environment. Increasing the level of autonomy in surgical robotic systems will help to standardize patient outcomes and free up surgeons for other tasks. Striving for higher levels of autonomy could be particularly useful in time-consuming and repetitive tasks such as suturing.

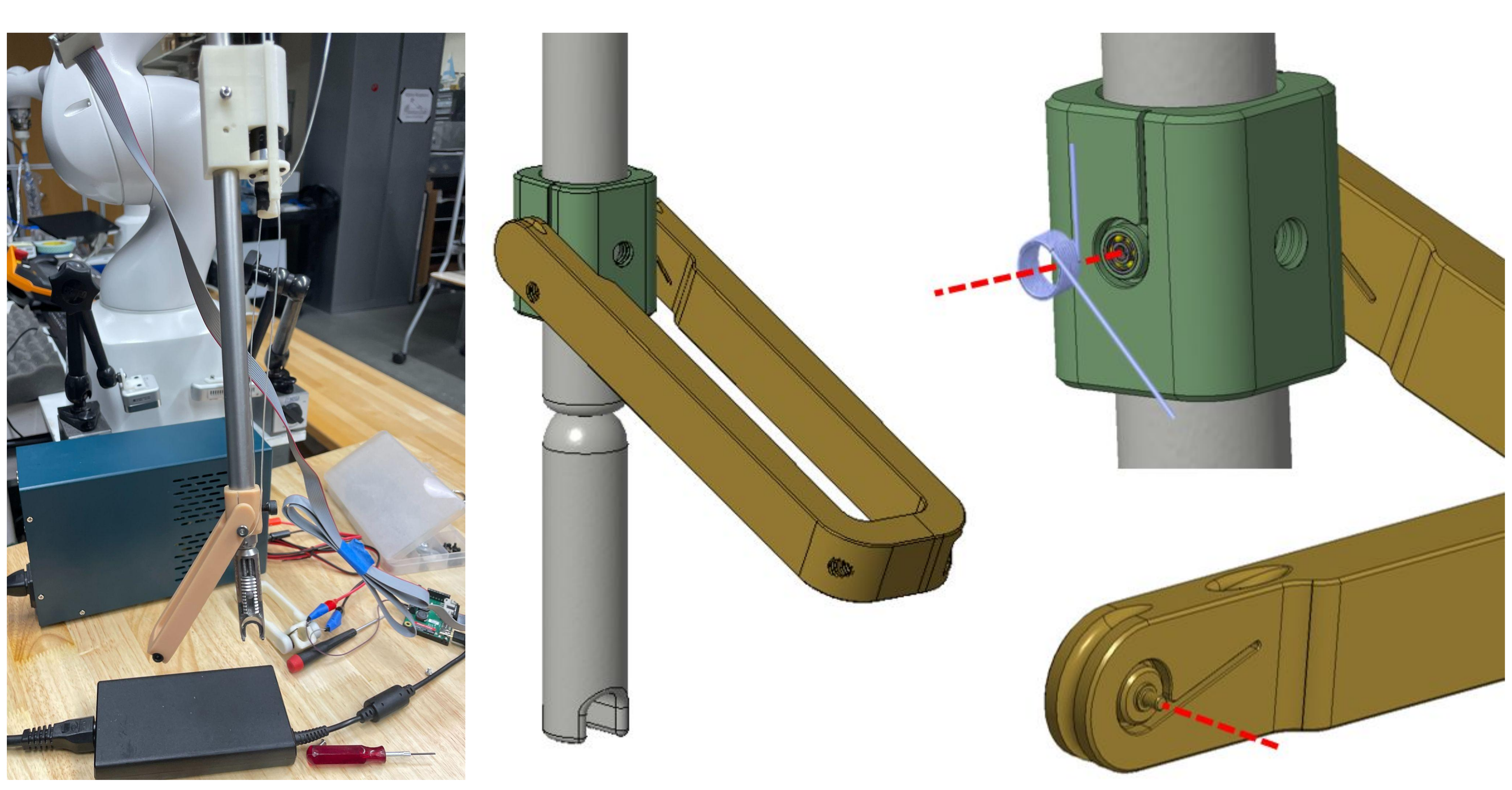

Full setup with the device mounted on the STAR robot

The Problem

- Early iterations of the STAR system have relied on a manual assistant to follow the autonomous end effector and perform suture tensioning management. This system is capable of operating within a laparoscopic workspace but is not fully autonomous [1].
- The latest STAR system uses a second autonomous arm in addition to the suturing end effector for autonomous suture tension management. This system has been shown to be effective and efficient, but its workspace could be too large to operate within a laparoscopic environment [2].

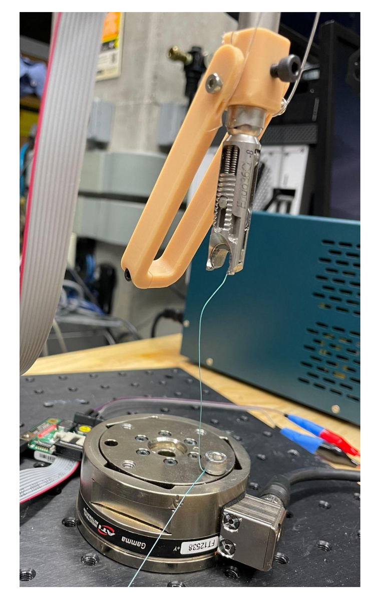
The Solution

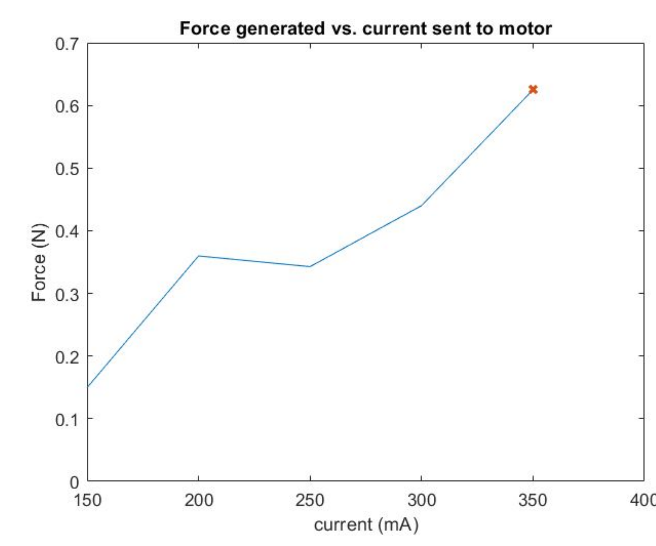
We designed, built, and tested a device designed to attach to the suturing end effector of the STAR system to allow for single-arm autonomous suturing in a laparoscopic environment. Our design is held in place at rest by a torsion spring at the pin joint which allows the device to sweep forwards to pull tension on the thread and then return to its resting position to avoid interference with STAR's suturing mechanism using only one motor. The device is cable-driven so that the motor can remain outside of the body and has a maximum diameter of 24mm to allow it to fit into a laparoscopic port.


Prototype of new suture tensioning device (left) mounted on an Endo360 suturing device. The device returns to its resting position thanks to the integrated torsion springs (right).

Testing and Results

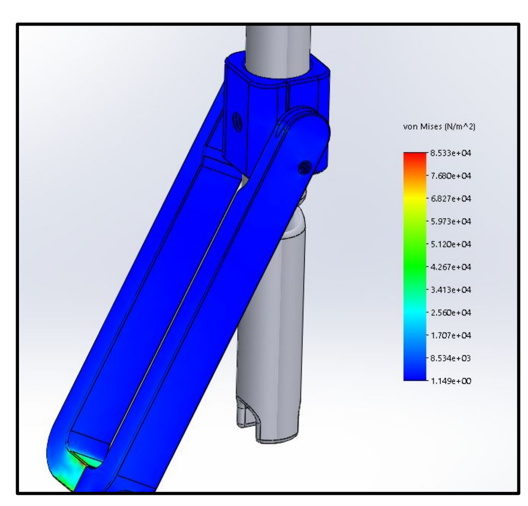
- We determined the maximum amount of force that our prototype was capable to exerting by fixing one end of a thread to a force sensor and the other to the STAR end-effector while gradually increasing the current (150-350mA) to the motor. Our device was stopped by the fixed thread and we measured the resulting force on the force sensor. The maximum force that the prototype was able to exert was 0.6N.

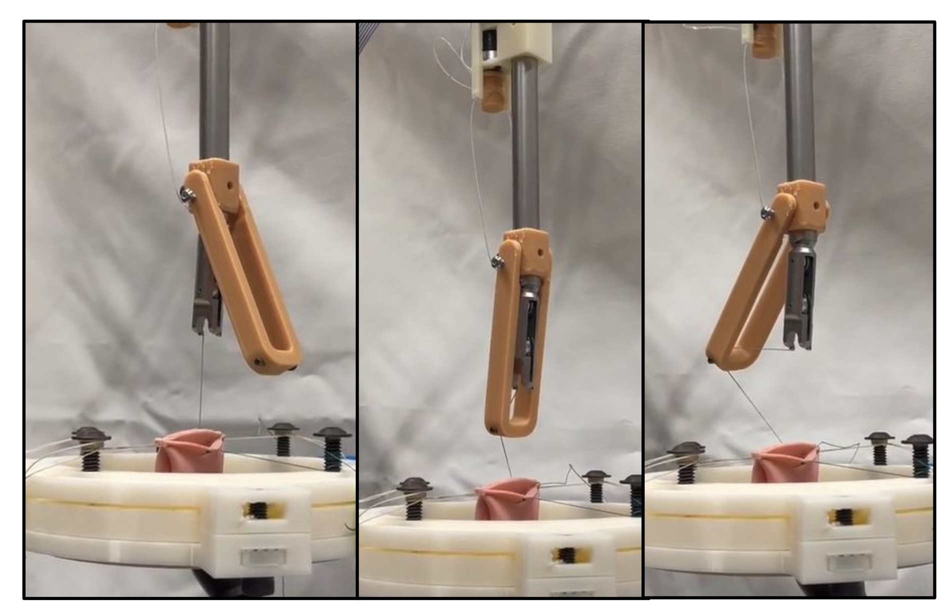

Force testing setup



Force testing results

- A finite element analysis was performed to verify that the design could hold up to forces of 1N without breaking. The maximum force that the prototype could withstand without deformation was 13.4N.
- We verified that our device was capable of pulling suture through synthetic bowel material by having STAR place one stitch in the synthetic bowel with our device to manage suture tension. The device was capable of pulling suture through the synthetic bowel.


FEA test results at 1N


Synthetic Bowel Testing swing mechanism in starting position (left), contact position (middle), and fully tensioning thread (right)

Future Work

- Continue to work towards miniaturizing the system for smaller ports than 24mm diameter.
- Document achieved work in a conference publication.

Lessons Learned

- The ordering parts process needs to be locked earlier. Some vendors are very slow.
- Multiple iterations of a physical prototype are ideal.

Credits

- We would like to formally thank our supervisors Dr. Krieger and PhD candidate Michael Kam for all of their support during the project.
- Nyeli was responsible for testing, Nathan for swing mechanism design, and Jiawei for transmission design.

References

[1] H. Saeidi et al., "Autonomous Laparoscopic Robotic Suturing with a Novel Actuated Suturing Tool and 3D Endoscope," 2019 International Conference on Robotics and Automation (ICRA), Montreal, QC, Canada, 2019, pp. 1541-1547
[2] S. Leonard et al., "Vaginal Cuff Closure With Dual-Arm Robot and Near-Infrared Fluorescent Sutures," in IEEE Transactions on Medical Robotics and Bionics, vol. 3, no. 3, pp. 762-772, Aug. 2021

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