Title & Author: ***Automating multi-throw multilateral surgical suturing with a mechanical needle guide and sequential convex optimization***

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Summary: The paper describes a methodology of using the DaVinci surgical machine to do completely autonomous multi-throw suturing (MTS) with the addition of a modified end effector called the Suture Needle Angular Positioner. They were able to demonstrate a success 50% of the trials albeit at a third of the speed of a human surgeon. To complete the task the authors developed a state machine where each step has several developments that allows this paper to see a reasonable measure of success. The first step involves aligning the camera and creating an initial needle pose estimation. Next they generate a trajectory that is replanned over a time increment in order to update the motion and account for deflection. At the end of the trajectory the needle is grasped on the other side and then since the path is planned along a constant curvature it is pulled out along the path of rotation. Each throw is concluded by pulling the slack out by moving the “hand” away from the stitch. This amount decreases by the distance of thread lost at each throw. The last step is to pass the needle back to the original hand which utilizes the SNAP as a sort of cage to reduce the force on the needle while the hands simultaneously switch the grasp. In addition to the complete autonomous MTS the effectiveness of the SNAP device is also evaluated at the conclusion of the paper. The authors found that the device massively improves the ability of the DaVinci system to grasp the needles given that it is able to grasp successfully even with up to 30 degrees of error in the needle position. The curved shape of the grasper and its several guides help to account for many types of failure in pose estimation or passing and the authors conclude that the SNAP makes robotics suturing much more attainable.

Strengths: The paper and its proposed techniques succeed in the consistency of the SNAP, the specificity of the problem formulation, and the explanation of the methodology. Firstly, the SNAP seems to show a high degree of success in spite of other failings of the system. Being able to make a needle handoff at a 30-degree angle miscalculation seems to me like a highly robust effector. While things like passing the needle or completing the sutures haven’t seen human levels of success yet the consistency of the grasp offered by the authors development shows great promise. In addition to the success of the development the paper itself has several elements that contribute to the success. The problem formulation at the start of the paper is specific and comprehensive. The setup of what the task to complete is (MTS) with the addition of the “stay-out zone” constraints makes it very clear of what the robot is trying to accomplish as well as the metrics that warrant success. By highlighting that the system is designed to do as little damage to the person as possible while making effective stiches makes understanding the work more intuitive. The last strength comes from the breakdown of tasks into a state machine. Dividing the elements into a sequence for discussion makes for nice divisions in which to discuss either where the system has difficulties (camera alignment) or where it sees improvement (trajectory planning and needle grasping). These specific boxes of discussion make future innovations or improvements easy to implement since the tasks are divided into reasonable length elements.

Weaknesses: The weaknesses of this paper come from the technique being slow and inconsistent. While it does see success in that it is able to complete an autonomous MTS most times the consistency is not close to what it would need to be to be used realistically, and the testing is very limited. The goal of the paper seems to be more about addressing the use of SNAP and their various innovations of control that have allowed them to piece together a complete suture procedure, but it fails at convincing me that this is even close to being an improvement over humans yet. There are also major elements that concern me about the robustness of the approach. Having a fixed distance for the stitch pulling instead of some sort of force sensing is incredibly dangerous. It seems not only more prone to errors but also being significantly more dangerous in the event of a mistake. Also, the number of failures that occur when the needle moves significantly inside the patient seems to be a major sticking point. The camera is supposed to help account for failures like that, but the detection is very poor. The task of needle detection is understandably difficult, but they were unable to successfully demonstrate consistency in a controlled environment with a yellow needle. It seems like this is a great demonstration that the task is doable, but I am not convinced that this demonstration is the best way to go forward.

Novelty: There are two major developments in this paper. The first is the ability to complete autonomous MTS for the first time. While the requisite elements have been completed separately, they are difficult to combine, and this paper shows the first such success in the field. This success comes from their ability to account for inaccuracies between each step and keep their needle pose estimation close enough to reality to be managed. Some of their techniques for keeping track of the needle include intermittent pose estimation while inserting the needle, the use of camera plane alignment for needle visualization, and constant curvature path planning. These techniques are not necessarily unique, but the consecutive use of them as a methodology for minimizing errors is novel. The second development is the SNAP attachment for use with the DVRK. The SNAP is a 3D printed guide for the needle that mitigates the uncertainty involved in needle grasping. It prevents rotation and provides for a more consistent positioning both while suturing and while passing the needle over. The design itself is mainly just a mitten that is slotted in several directions to add onto the DaVinci while suturing. This paper presents lots of technical elements that improve the confidence of the system that have already been developed but sees them put together with some new developments to be able to perform longer suturing tasks than were previously possible. So while it isn’t necessarily pioneering it is a well designed innovation and use of discovered knowledge.