Review of the paper titled

"Cable Length Estimation for a Compliant Surgical Manipulator"

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As a part of EN.600.446 CIS II, I am reviewing the above mentioned paper which has relevance to my project 'Interfacing APL Snake end effector to the LARS' (Group 3). The main aim of the project is to interface the APL Snake end effector to the LARS and achieve end-point control. It is being carried out by me and my partner Ashish Kumar under the guidance of our mentors Mehran Armand, Ryan Murphy and Michael Kutzer. The image presented below is a close representation of the work we aim to achieve. The image is from the CIS II report of H.T. Sen who worked on similar project in 2010.

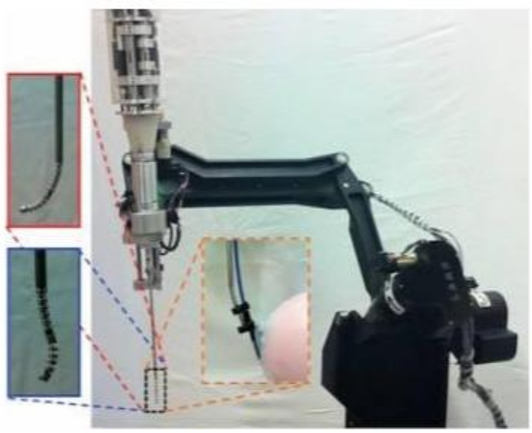

Image from: Tutkun Şen: *Elastography with LARSnake Robot*

Reason for selection of the paper: The paper discusses the control of 'APL Snake', which is one of the key components of my project. It acquaints the reader with initial challenges faced to control the movement of the manipulator. However, the primary reason for getting acquainted with the control of the snake was to be able to help my mentors in resolving a dependency which might appear in future, where complete actuation control of the Snake has to be achieved. Also, it is fitting that understanding and reviewing this paper gives an opportunity to us as well as mentors to improve on the larger project of which my and Ashish's project is a part of.

Summary of the problem: In 2011, the authors had presented a design of an under-actuated, hyper redundant, snake-like manipulator for surgical removal of osteolysis behind total hip arthroplasties. Designed by researchers at the JHU and APL, the manipulator has been nicknamed the APL-Snake. It was primarily controlled in a single plane using two independently actuated cables. However, cable length estimation for the actuation remained a challenge. Optimum length of cable, limit points, material for the cable posed as several questions in the minds of the researchers.

Key Result: The primary achievement of this paper is in being able to predict the cable length from a given configuration and vice versa. The accuracy in this method is fairly good and there was also a repeatability of results after few initial use of the cable. The result is all the more significant because:

i> The presentation is detailed and articulated.

ii> It removes any ambiguities whatsoever, regarding methods of cable length estimation.

iii>Clarifies the reason for using '304 stainless steel'.

Flow of the paper: The authors have maintained a continuous workflow in the paper while addressing various issues in depth. After defining the background of the project and problem being faced, the authors choose to review the manipulator and kinematic model of the APL Snake. Next they move on to cable length prediction algorithm which is the primary motive of the paper.

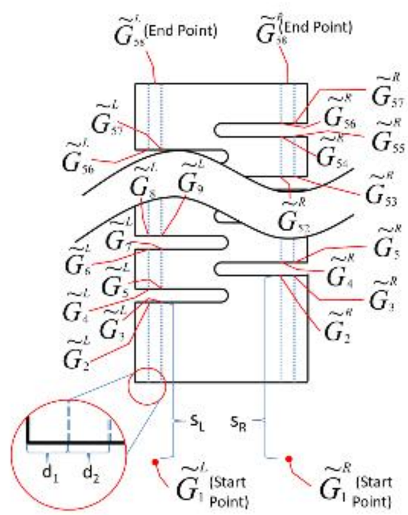

Fig 2. Cable channels. (Image taken from the paper)

Initial condition for the process is that when fixed to the ends of manipulator, the cables are centered in the top of their respective channels. The diameter of the channels is 0.69mm which is more than double the diameter of the drive cables (0.254mm). This should facilitate resistance free movement of the cable. However, constant curvature of the cables cannot be assumed since they rest along the walls in case of bending of the Snake. The authors use Dijkstra's algorithm to calculate the shortest path using distance weighted graph of valid connections between channel boundary points. Problems of cable yielding and deformation are addressed by the authors. They claim, after initial 3-5 cases of use of the cable, the cable achieves a rigid length and is not deformed further.

Strengths of the paper:

- The work is detailed and explanatory.
- Authors have taken utmost care while addressing problems such as cable yielding, cable slip and elastic deformation.
- Repeatability and accuracy of the algorithm have been verified by the authors over various set of experimental conditions.

Weaknesses of the paper:

- Complications in this method would increase if more DoF is desired.
- The paper doesn't enumerate comparison with any other material for construction of cables.
- The authors have taken liberty of assuming zero friction between cable and manipulator which is a very ideal case and may not be practically feasible.
- There should have been mention of the specifications of stepper motors being used.

Possible next Steps for this work:

The authors have mentioned their current involvement in developing a new actuation unit to eliminate cable slip entirely. They should also incorporate the estimation of friction between the cable and manipulator walls. A more challenging work shall be to consider the case of tool being guided through the Snake.

Conclusion: The suggestions for improvement were discussed with our mentor. I was updated with the improvement in this regard. The draft of paper to be presented this year addresses various issues. The algorithm provided in this paper, however remains the basis of future work.

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