CIS II Seminar Report

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1. Paper Selection

To extend workspace and achieve the optimal tool manipulation angle in the robot assisted eye surgery, additional freedom to the original steady hand eye robot (SHER) will be very useful. Integrated Robotic Intraocular Snake (IRIS) is such a way proposed by Hopkins researchers to do this work. However, IRIS project is not really finished, because a good control scheme is still needed to help surgeon carry out operations intuitively and efficiently. The eventual goal will include the integration of IRIS and SHER so that surgeon can use Phantom Omni as an input to directly control the IRIS tip position and orientation while maintaining the remote center of motion on the sclera.

Because IRIS is the first snake robot of its kind that is made in sub-millimeter scale. There is less available reference about intraocular snake robot. However, some similar snake robot research in different field is also very motivating. In this seminar, a research work on a bigger snake robot for pelvis surgery including two papers will be presented. The first paper [1] mainly addresses the issue of snake robot design, kinematics and how to use string length to predict the snake robot bending, given that the bending curvature is not a constant. The second paper [2] is based on the first paper and it investigates how to integrate the snake with the UR5 and achieve coupled motion control. They approach this target by solving a constrained optimization problem.

2. First paper: Snake kinematics and non-constant curvature bending prediction

The design of the pelvis snake robot is shown in figure 1. No articulation is made in this robot: it is made of a whole piece of metal, which is elastic nitinol. By cutting notches on the side of the cylinder, it enables bending in a plane through the pulling of the strings on one side. During operation, the snake will be inserted through an acetabular implant.

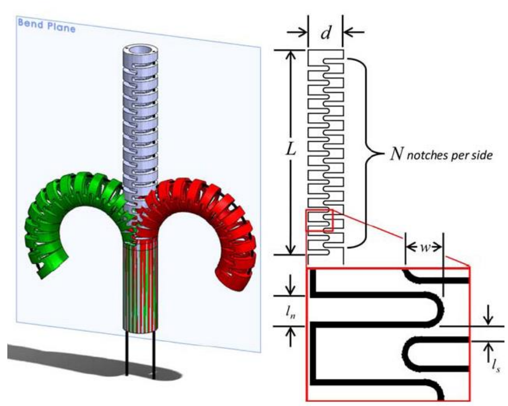

Fig.1 Pelvis snake robot design

Although many snake robot paper assumes that the bending curvature is constant, in this paper a way to capture the non-constant curvature behavior is presented. It is achieved mainly through experiment-based model fitting. The red dot in Fig.2 denotes the end-effector position, which is p_e. First, we find the x coordinate by a Bernstein basis polynomial which takes L as input. L is the length of string pulling translation. Then we can use the x coordinate to find the z coordinate through the sum of three sinusoid. Later the parameters of these models can be obtained from experiments. After we find the tip position, we can find all θ's of snake configuration by finding the minimal system energy. Here they model the joints as springs with same spring constant.

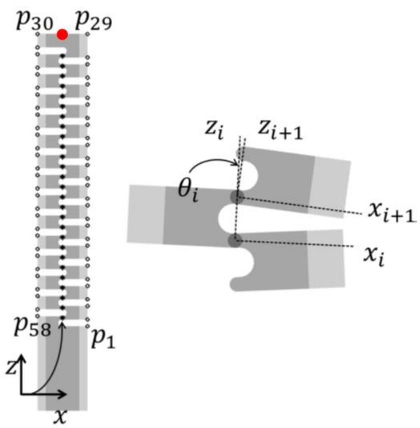

Fig.2 Bending behavior of pelvis snake robot.

In Fig.3 it shows the experiment setup. Basically, a vision system is used to capture all segment-wise bending angles. The snake is bent to maximum angle in discrete steps, and all sensor feedback, including camera captures and force sensor detections, are recorded for model fitting.

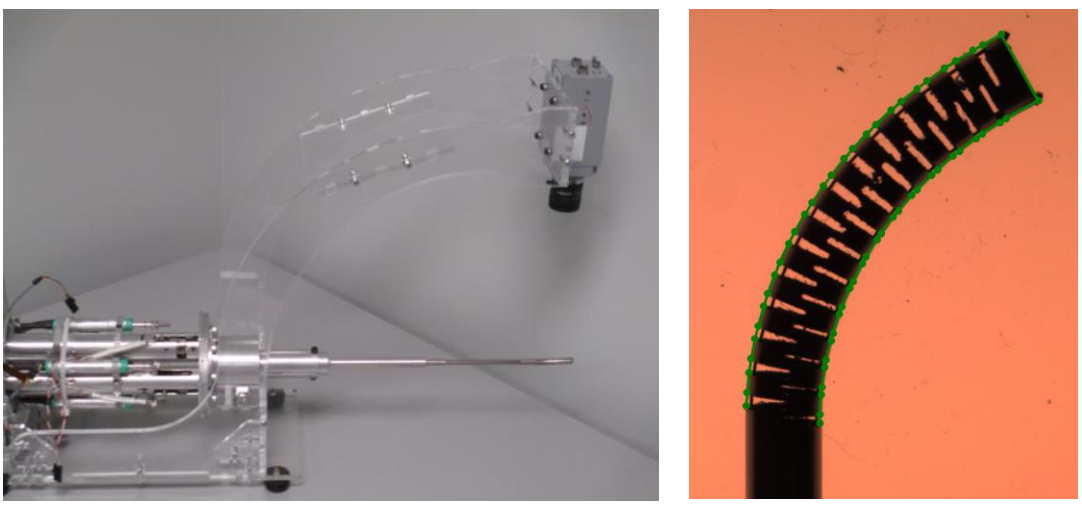

Fig.3 *Left*: Vision based bending measuring system. The manipulator is manually aligned to bend in the image plane. *Right*: Overhead view of the manipulator with an outline of the manipulator projection found from the registration technique overlaid

The result is show in Fig. 4. The actual tip trajectory is different from that based on constant curvature assumption. Which deviates at about 3.5 degree of segment-wise bending angle. Also, we have 58 landmark points on the snake, the predicting error for each point are shown in the Fig.4 *Right*. The maximal error is the tip error, which is about 1.1 millimeter on average.

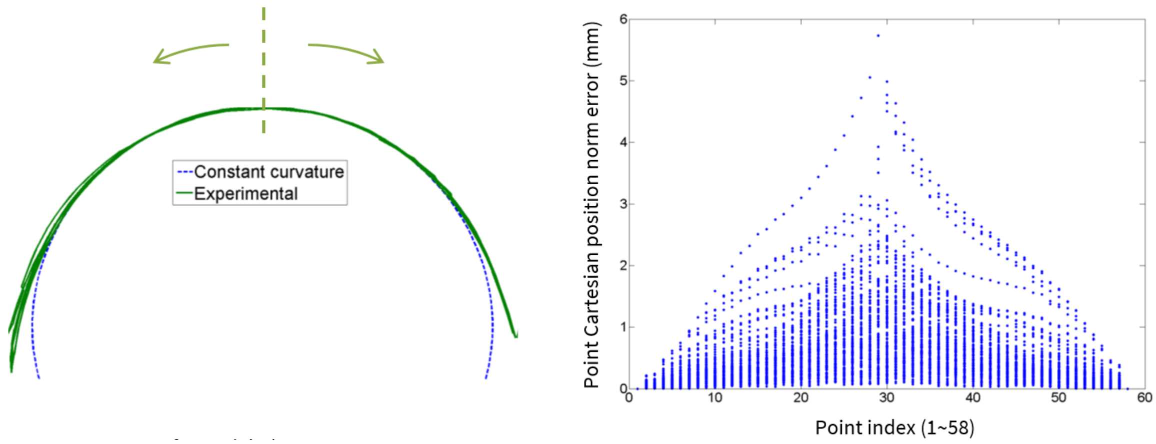

Fig.4 Experiment results

3. Second paper: Control of UR5-Snake robot coupled motion

To investigate the coupled motion. First, we can investigate the UR5 kinematics and Snake robot kinematics separately. The snake robot model is just using what we established in the first paper. Now we want to integrate the two models. After some coordinate transformation and combination, we can establish the coupled Jacobian matrix of the integrated system. Here the joint velocity input $\dot{q}$ has 7 independent variables, 6 from ur5 and 1 from snake robot.

Because during the pelvis osteolysis treatment, the integrated system should be constrained at the RCM point. The control algorithm is based on solving the constrained optimization problem. First, we estimate current joint position $\dot{q}$, and compute the incremental motion. Transform it into cartesian space. Solve the optimization problem and update the robot state. The algorithm is shown in Fig.4 below.

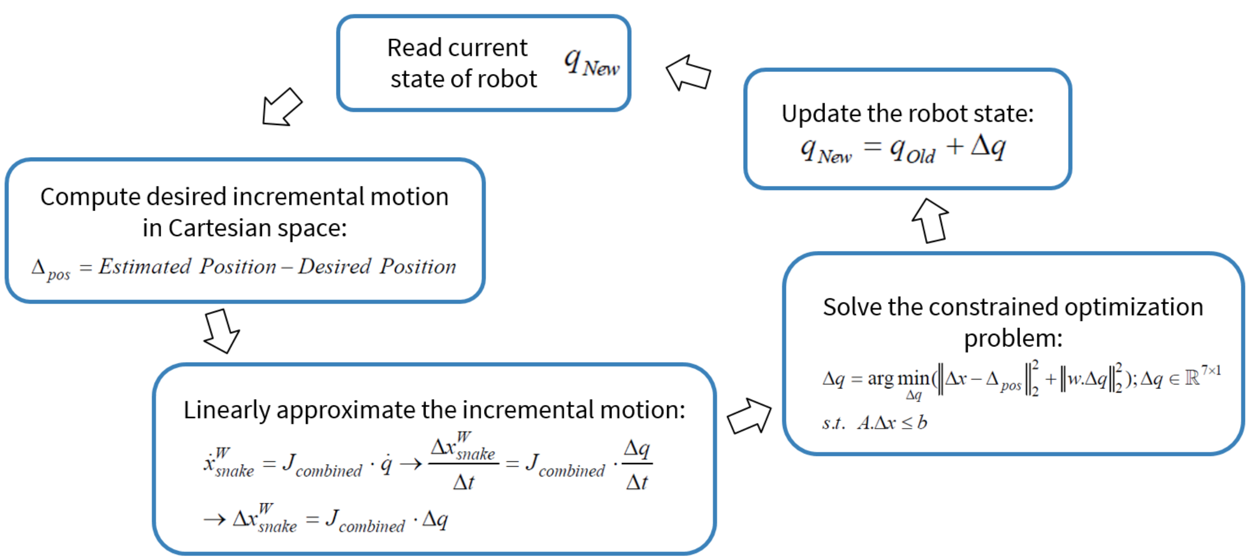

Fig.4 Coupled robot motion control algorithm

The constraints in the optimization problem approximates the cylinder constraint as a polygon constraint. Also, we have snake robot string length constraint. Combining this, the constraint is set up.

The authors validate their work through simulation. In Fig.5, the output tip trajectory follows well with the desired path, except for some occasional deviation during sudden change of movement.

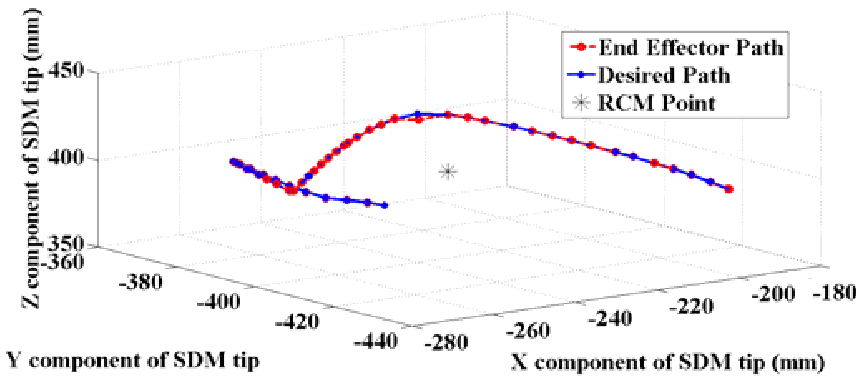

Fig.5 Simulation validation

4. Motivations

First, we can compare the snake robot design. Except for that our robot is 2DOF robot, the main difference is that IRIS is designed to be a constant curvature robot, because there is no spring effect in the structure. However, because in such a micro scale, concept will not always work, the bending of IRIS is non-linear. Therefore, we can possibly use their method to estimate the bending of IRIS. This paper present a general way to experimentally identify the relationship bending angle and string translation, through the steps we have discussed above. Because of the structure of IRIS, the movement of 2DOF can be combined directly by 2 1DOF movement, which enables technique to be extended to 2DOF.

Besides, the robot integration control algorithm also give us some inspiration how to control the coupled motion of IRIS and Steady hand eye robot. The two systems are very similar in this aspect. From the second paper, we are motivated to use a constrained optimization technique to deal with the coupled motion of two robots.

Finally, there are some other motivations like using the vision system to obtain sub-degree accuracy of bending angle. Also, we can use the same way to find the home position of the snake as they do in the first paper. In general, we have obtained many useful information from comparison with other snake robot systems.

References

[1] Murphy, Ryan J., et al. "Predicting kinematic configuration from string length for a snake-like manipulator not exhibiting constant curvature bending." Intelligent Robots and Systems (IROS 2014), 2014 IEEE/RSJ International Conference on. IEEE, 2014.

[2] Alambeigi, Farshid, et al. "Control of the coupled motion of a 6 DoF robotic arm and a continuum manipulator for the treatment of pelvis osteolysis." Engineering in Medicine and Biology Society (EMBC), 2014 36th Annual International Conference of the IEEE. IEEE, 2014.