Hydrophone Sensing Integration with APL Snake Robot

Project Proposal

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Summary and Goals

The goal of this project is to create a system that utilizes data from one or more optical hydrophones integrated into APL snake robot to determine the location of the robot manipulator tip. The project would consist of building circuitry to process the analog signal from the optical hydrophone, writing software to gather digital data from the circuitry, software to control pulse timing of an ultrasound machine, and software to integrate all the data and determine manipulator location.

Motivation

The APL snake robot is to be used in removal of osteolysis caused by hip implants. The procedure involves drilling a hole into the pelvic bone and inserting the snake manipulator which removes the osteolytic bone. Current control methods can not accurately determine the position of the manipulator tip under external forces, so a method of accurately determining the tip through external measurements is required.

Technical Background

Ultrasound is sound with frequencies above the threshold of human hearing (50kHz). Typical frequencies for medical imaging are in the range 1 MHz to 20MHz. Modern ultrasound transducers use an array of piezoelectric elements that can be activated in sequence or tandem to get a focused beam or scanning series of beams.

An optical hydrophone consists of a fibre-optic cable with a Fabry-Perot interferometer attached to one end. A laser beam of frequency matching the resonance of the interferometer's unstressed state is transmitted down the optical fibre and a machine measures the strength of the reflected signal. When ultrasound hits the end of the fibre-optic cable, the distance between the two reflective layers of the interferometer changes and a corresponding change in the reflected laser light is sensed by the controlling machine.

Technical Approach

For the minimum deliverable of determining tip position, a single hydrophone fibre-optic cable will be inserted into the manipulator of the snake robot. A linear array ultrasound probe with 128 transducers that can be separately controlled will be used to create signals to be picked up by the hydrophone. An EM tracker marker or set markers will be attached to the ultrasound probe so that its position and orientation can be tracked by an external EM tracker. Each of the 128 transducers will be pulsed in turn and the time between pulse initiation and pickup by the hydrophone will be measured. This time and the estimated speed of sound in tissue (1540 m/s) will be used to determine the distance between the transducer and the manipulator tip. The ultrasound probe will then be moved perpendicular to the linear array to get a second set of out of plane readings. Once two linear scans are complete, the position of the manipulator tip will be calculated by triangulation.

Due to the high frequency of the ultrasound used (10 MHz), a specialized circuit will be used to rectify and integrate the analog waveform from the optical hydrophone. This will greatly simply sampling and allow greater time resolution when finding time of flight of ultrasound pulses.

To calculate the angle of the ultrasound probe two methods can be. One method is using two optical hydrophones inserted on opposite sides of the snake robot manipulator and measuring the phase shift between the two analog waveforms they pick up. This would allow a very high time resolution between time of flight of the two points. Triangulation as before would then allow calculation of the vector between the two points. The constraint that this vector lies on the plane of the robot manipulator's tip, combined with the modeled robot kinematics and calculated position would then allow a more accurate estimate of the manipulator tip's orientation.

Deliverables

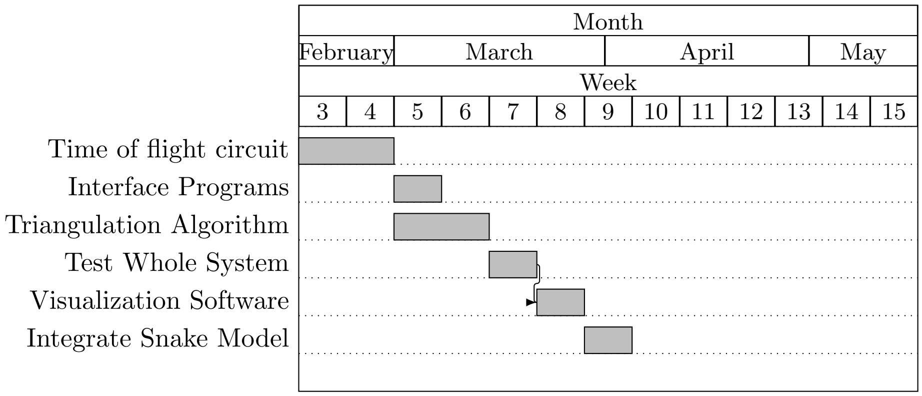
- **Minimum:** Circuitry and software to determine hydrophone tip position within 5 mm.
- **Expected:** Hydrophone integrated into snake robot manipulator.Circuitry and software to determine hydrophone tip position and orientation within 5 mm and 10 degrees. Basic visualization of position.
- **Maximum:** Hydrophone integrated into functioning snake robot. Circuitry and software to determine hydrophone tip position and orientation within 1 mm and 10 degrees. Real time visualization of manipulator combined with ultrasound or CT scan data.

Checkpoints

1. March 4: Complete circuit on Arduino board to time ultrasound travel time.
2. March 11: Complete program to interface with EM tracker, ultrasound machine, and Arduino driver programs
3. March 18: Complete triangulation algorithm.
4. March 25: Test all components together (circuit, interface, triangulation)
5. April 1: Complete rudimentary visualization program
6. April 7: Interface previous software to snake control program; use existing software model or create new model for snake robot kinematics

Dependencies

Dependency	Resolution Plan	Action on failure	Required date
Ultrasound machine	Acquired	NA	NA
Fibre-optic hydrophone	Acquired	NA	NA
Pelvis model	Animal bone from butcher	Do without	April
Arduino board	Pick-up 2/20	Buy ($20), delay circuitry	March 4



Management

Weekly meetings (day and time not yet arranged).