JOHNS HOPKINS UNIVERSITY

LABORATORY FOR Computational Sensing + Robotics THE JOHNS HOPKINS UNIVERSITY

Hydrophone Sensor Integrated with APL Snake Robot

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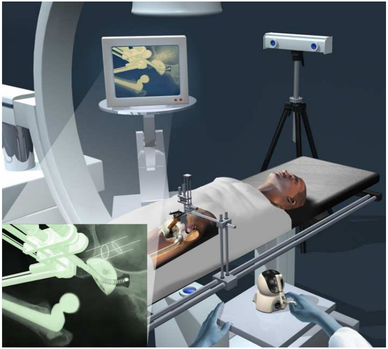
Goals

1. Integrate one or more optical hydrophones into the current APL snake robot manipulator to allow accurate ultrasound readings of tip position.
2. Develop software framework to allow communication between ultrasound machine, EM tracker, robot control system, and optical hydrophone.
3. Visualize position data in useful and visually pleasing way (similar to Robodoc)
4. Develop general purpose calibration methods

Motivation



Kutzer et al.

Current method

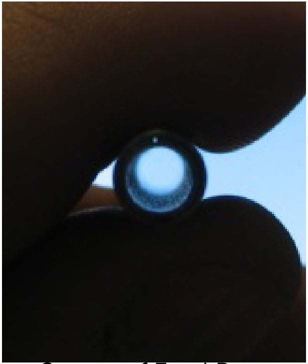
- Inaccurate
- Limited mobility
- Insufficient

Improvements

- Direct measurement
- Accuracy ($\leq$ 1.3 mm)
- Improved visualization

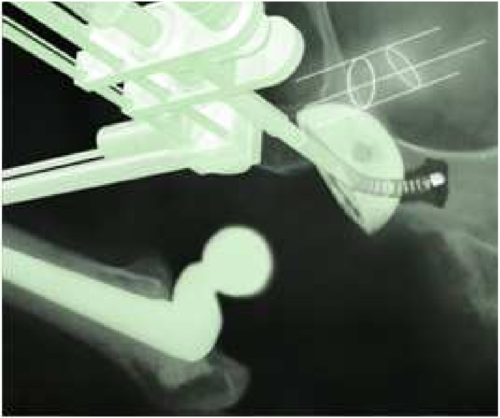
Implementation plan

- Optical hydrophone in end-manipulator
- Measure ultrasound at tip
- Calculate US time of flight
- Multilateration from multiple sources
- Display data back to operator



Courtesy of Emad Boctor

Use case scenario



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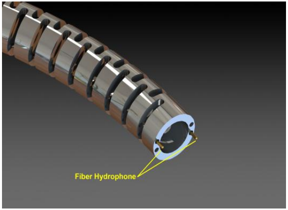
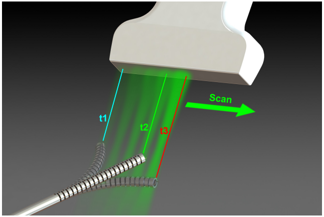


Courtesy of Xiaoyu Guo



Courtesy of Xiaoyu Guo

Use case scenario

Kutzer et al.

Deliverables

Minimum

1. Software and circuitry to measure time of flight
2. Able to determine manipulator position within 5 mm

Expected

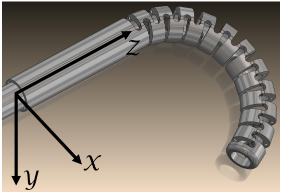
1. Software and circuitry to measure time of flight
2. Able to determine manipulator position within 1 mm
3. Rudimentary visualization, shows position

Maximum

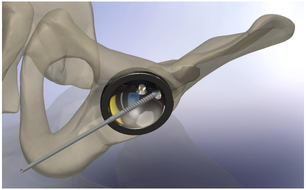
1. Software and circuitry to measure time of flight
2. Able to determine manipulator position within 1 mm
3. Able to determine manipulator orientation within 5 degrees
4. Clean visualization, shows progress, material to remove

Previous concerns

1. Hydrophone fibre curvature
   - Results unaffected down to 2cm radius
   - Noticeable attenuation at 1cm, but fibre unharmed
2. Lensing anatomy
   - Can use prior CT scan data to estimate refraction
3. Ultrasound penetration
   - ≈85% reflection at tissue-bone interface
   - ≈2% penetration
   - But, only need binary signal, noise may be issue
   - Still need to test with real bone

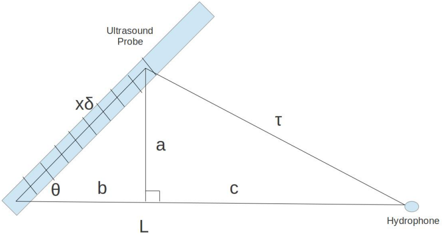


Liu et al.



Liu et al.

Calibration for element spacing



$$\tau^2 = a^2 + c^2$$

$$L = b + c$$

$$a = x\delta \sin\theta$$

$$b = x\delta \cos\theta$$

$$\begin{aligned}
\tau^2 &= a^2 + c^2 \\
&= (x\delta \sin\theta)^2 + (L - b)^2 \\
&= x^2\delta^2 \sin\theta^2 + L^2 - 2Lx\delta\cos\theta + x^2\delta^2\cos\theta^2 \\
&= L^2 - 2Lx\delta\cos\theta + x^2\delta^2
\end{aligned}$$

Calibration for element spacing

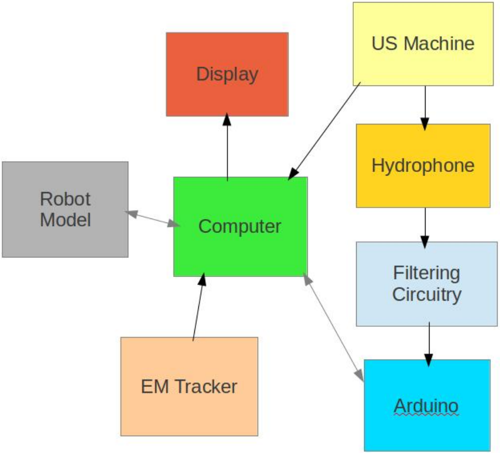
$$\tau^2 = L^2 - 2Lx\delta\cos\theta + x^2\delta^2$$

- Perform non-linear least squares on 128 elements of array.
- Treat τ^2 as y, $L, \delta,$ and θ as parameters to solve for to minimize residuals.
- Used simulation and Gauss-Newton method to test, worked well for measurement errors below 5%, more complex techniques required to make it more robust.

EM-US calibration

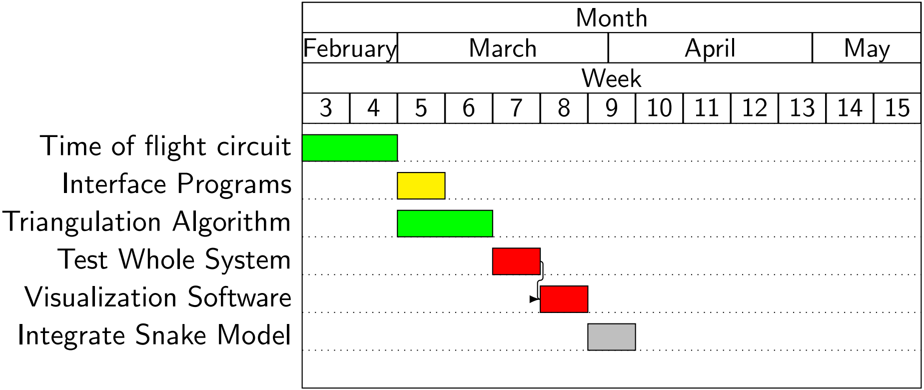
- Use parameters from previous slide for two probe positions
- If position and orientation of probe known for both samples, can use the L and θ for each to determine the position of US array in frame of the US probe
- Possible to do with US imaging and fiducial, but wanted to find another method to simplify process

Workflow

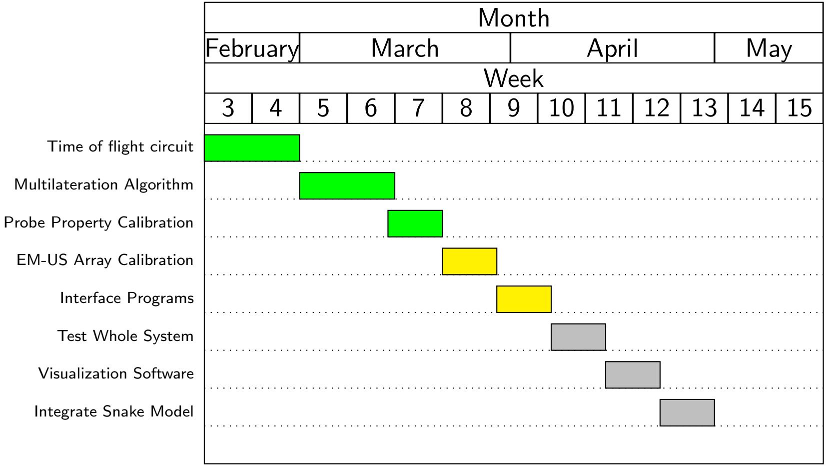


Display
US Machine
Hydrophone
Robot Model
Computer
Filtering Circuitry
EM Tracker
Arduino

Old Schedule



New Schedule



Deliverables

Minimum

1. Software and circuitry to measure time of flight
2. Able to determine manipulator position within 5 mm

Expected (additional)

1. Able to determine manipulator position within 1 mm
2. Rudimentary visualization, shows position
3. General purpose calibration methods

Maximum (additional)

1. Able to determine manipulator orientation within 10 degrees
2. Clean visualization, shows progress, material to remove

Bibliography

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Thanks

Questions?