Tracked Ultrasound Calibration

Ultrasound (US) is ubiquitous in modern health care environment, providing information support by visualizing anatomy beneath the organ surface. It enables noninvasive real-time visualization without using ionizing radiation and is relatively inexpensive. One way to extend the utility of US into interventional medicine is to augment the US transducer with a tracking system. Once tracked and calibrated, as an example, freehand 2D US image can be reconstructed to form a 3D US volume to provide better visualization and to serve as basis for volume-based registration with other imaging modalities.

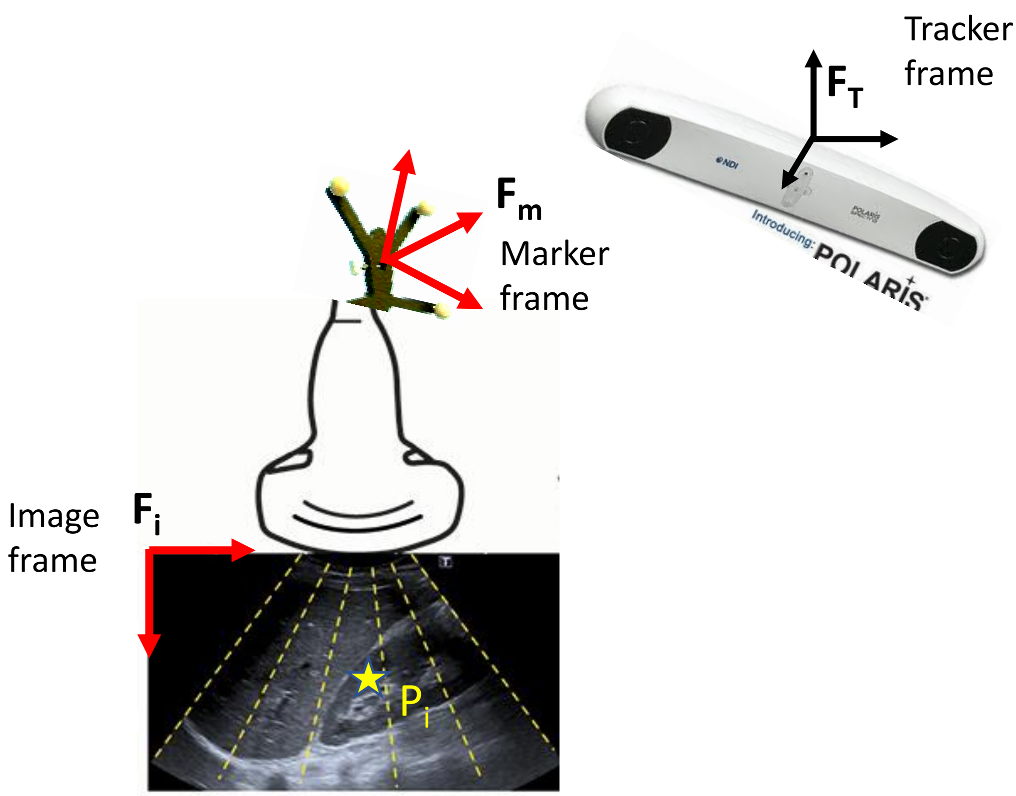

Fig. 1

Transformation Pipeline

Annotate Figure 1 with the relevant frame transformations.

Express an image point (P_i) in the tracker coordinate system (P_t) with frame transformations.

Express a tracker point (P_t) in the image coordinate system (P_i) with frame transformations.

Ultrasound Calibration

Ultrasound calibration refers to the process to determine the geometrical relationship between the US image to its pose sensor markers; a frame transformation between F_m maker frame and F_i image frame in Figure 1. Your task will be to design and develop a method to determine the unknown frame transformation between F_m maker frame and F_i image frame.

To carry out the calibration, you have a tracked and pre-calibrated pointer like the one in the Fig 2. We assume that from the readings of the tracking markers the tip of the pointer is known in in the tracker coordinate system. You also have a water tank filled with water (Fig3). You can submerge the pointer tip in the tank and acquire images with the ultrasound while you are. Tracking the probe. You then can save and process the images on your computer and localize the pointer tip in the US images.

Fig. 2

Fig. 3

Calibration Math

Using the, tracker, pointer and water tank, design a method for carrying out the calibration. Explain the process, derive the requisite mathematical formulation using frame transforms etc. to obtain the $F_{t->i}$ frame transformation. Make a figure, annotate as necessary.

Calibration Implementation

Implement the ultrasound calibration method in MATLAB. Design the input as necessary. The output is $F_{i->m}$ frame transformation.

Ground Truth Arrangement

Design a suitable simulated ground truth arrangement. Think about CISC 330 Surgical Drill Calibration assignment, where you were free to design a hypothetical drill with hypothetical markers and place it with a hypothetical tracker, all conveniently arranged. You are free to design any arrangement that is mathematically suitable for the calibration purpose. Pre-determine the ground truth frame transformation parameters. Make a figure, annotate, etc.

Ground Truth Test

Generate a handful (N=20) of known ground truth probe calibration poses with your hypothetical ground truth tracked US transducer. Design and explain what poses you will use. Run your calibration code and ascertain that you can get back the ground truth $F_{i->m}$ frame transformation.

Workflow optimization

What are the potential pitfalls of this calibration method, what are the main sources of inaccuracy? Recommend approaches to make it more robust and more accurate.

GENERAL RULES

- Read the online syllabus carefully for general instructions on the submission of assignments.
- Always explain how you solve a problem. Use drawings, math formulas, text, block diagram, pseudo code - anything that you find them appropriate to convey your ideas. I must know that you understand what you are doing and I must be able to follow your reasoning. Depending on the quality and depth of your reasoning and discussion or results you may pick (or lose) lots of points.
- Write proper header and richly comment your code. There is no such thing as too much comment. Good style and neatness will earn you valuable points. The lack of these will cause reduction.
- Use decimal digits sensibly and consider what is precision is practical for the given problem. Generally, resolution much finer than 1 mm is not practically achievable, so use 0.1 mm as your. Use integer or decimal point format in your outputs. No exponential number format!
- Test each module fully and construct several test cases with known ground-truth answer. Construct the examples “on paper”, explain the result that you expect, then run the example through the code and show that your program is correct – it produces the ground truth you pre-computed.
- Write a testing m file(s) for each module or problem.
- Capture the output, to show that your program does what it is supposed to do. Make plots whenever it is requested or makes sense. Add explanation text as you see it useful.
- Use MATLAB routines for recurring tasks.
- Submit the m files and the captured output file, as well as any drawing, or supplemental information you feel relevant.

Have fun!

Tracked Ultrasound Calibration Grading Points

Transformation Pipeline		**10**
Annotation	5	
Math	5	

Calibration Math		**25**
Design	10	
Math	15	

Calibration Implementation		**10**
Design		
Implementation	10	

Ground Truth Arrangement		**25**
Design	15	
Ground truth	10	

Gound Truth Test		**30**
Design	10	
Implementation	10	
Runs and tests	10	

Workflow optimization		**15**
Pitfalls	5	
Sources of error	5	
Methods of improvement	5	

TOTAL **100**