# Homework Assignment 5 – 600.455/655 Fall 2021

## Instructions and Score Sheet (hand in with answers)

| | |
|---|---|
| Name | Name |
| Email | Email |
| Other contact information (optional) | Other contact information (optional) |
| I have followed the rules in completing this assignment<br><br>(signature) | I have followed the rules in completing this assignment<br><br>(signature) |

| Question | Points | | Question | Points | | Total |
|---|---|---|---|---|---|---|
| 1 | 40 | | | 3a | 15 | |
| | | | | 3b | 5 | |
| 2a | 20 | | | 3c | 5 | |
| 2b | 15 | | | 3d | 5 | |
| 2c | 15 | | | | | |
| | | | | | | |
| | | | | | | |
| Subtotal | 90 | | Subtotal | | 30 | 120 |

**Note: There are 120 points on the assignment, but the most that will count toward your course grade is 100.**

1. Remember that this is a graded homework assignment. It is the functional equivalent of a take-home exam.
2. You are to work **alone or with your partner** and are **not to discuss the problems with anyone** other than the TAs or the instructor. **(NOTE:** You are strongly encouraged to work with a partner).
3. It is otherwise open book, notes, and web. But you should cite any references you consult.
4. Please refer to the course organizational notes for a fuller listing of all the rules. I am not reciting them all here, but they are still in effect.
5. Unless I say otherwise in class, it is due before the start of class on the due date posted on the web. See the course organizational materials.
6. Sign and hand in the score sheet as the first sheet of your assignment.
7. You will submit the assignment in PDF form to Gradescope, as discussed in class.

# Scenario: US-guided Intervention – Navigation and Quality Control

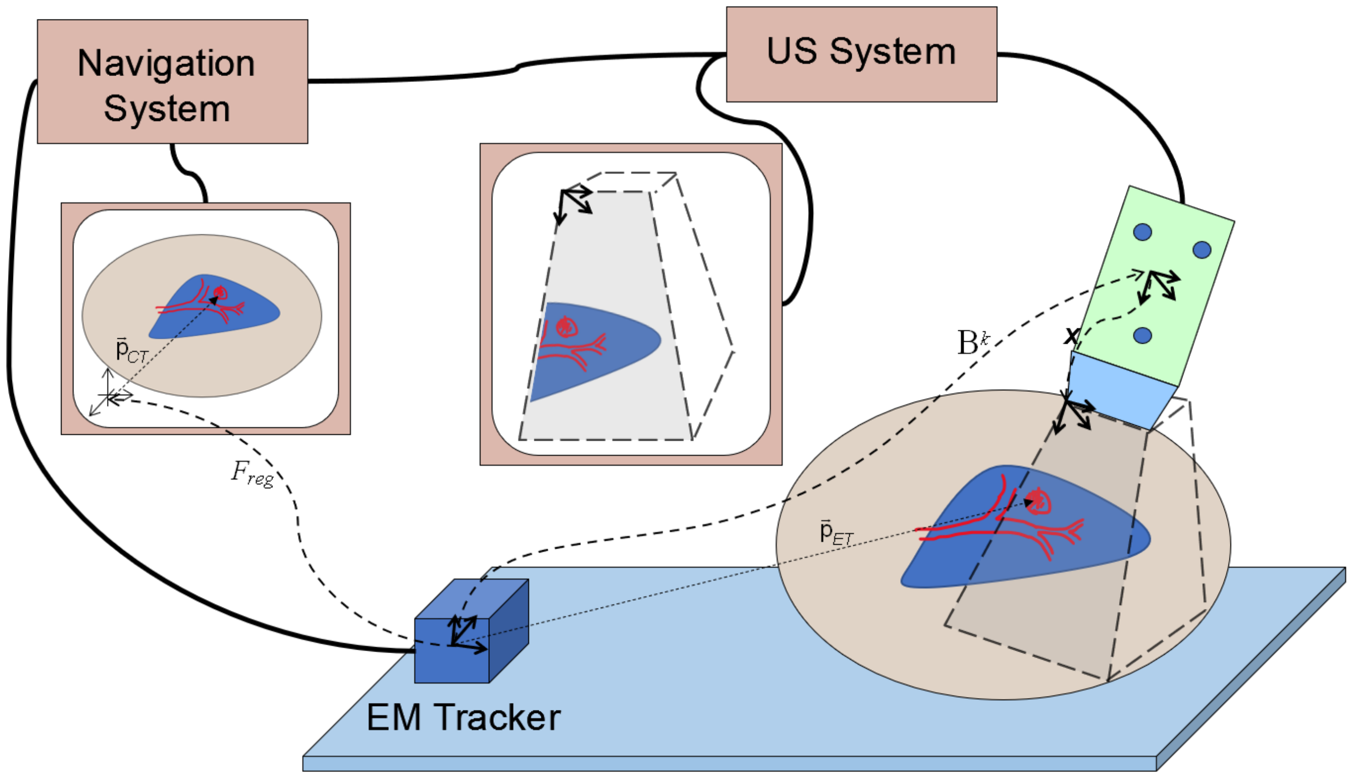


**Figure 1 Overall Navigation Setup**

Consider the 3D ultrasound system shown in Figure 1. Suppose that your calibration of the ultrasound probe (***X***) has been successful from homework #4, and now you have the 3D ultrasound probe calibrated as well. ***X*** is a frame of transformation with a rotational component $R_X$, and a translational vector $\vec{p}_X$. Suppose that the 'Z' calibration phantom from homework #4 is removed, and a patient is introduced, as shown in Figure 1.

## Questions

1. A CT scan of the patient is available, and a suspected tumor has been found in the CT image. A planning system has determined that a good place to biopsy this tumor is at location $\vec{p}_{CT}$ relative to CT coordinates. In order to biopsy the tumor, the target coordinates $\vec{p}_{ET}$ relative to the EM tracker must be determined, which, in turn requires the computation of a registration transformation $\mathbf{F}_{reg}$ such that $\vec{p}_{ET} = F_{reg}.\vec{p}_{CT}$. The tumor is not visible in ultrasound images,

but some nearby structures are visible in both CT and ultrasound images. Further segmentation software is available to determine the exterior surfaces of these structures. Describe a method for determining $\mathbf{F}_{reg.}$. Provide sufficient step-by-step detail and pertinent formulas so that your method is clear.

2. Suppose that your method has succeeded in computing $\mathbf{F}_{reg.}$ to very high accuracy. Because, the patient is stationary, the organ of interest doesn't have motion artifacts, ultrasound capture is quick, and the registration algorithm is very stable. However, right before the planned intervention, several tools and equipment were introduced to the surgical room. Unfortunately, a couple of these needed tools may cause serious interference with the EM tracking system. The distortion is presented in the tracking readings as follows: $\widehat{B}^{k} = B^{k} \Delta B$. (For the purpose of this problem, we will make the slightly unrealistic assumption that $\Delta B$ is constant over the range of the scan). The doctor wants to perform a routine quality control check.
    a. Without relying on external optical tracking system or any additional hardware, please suggest a method to detect the presence of this field distortion. (Hint: Consider the patient CT as a calibration phantom!)
    b. Suppose we don't have access to the patient CT. We still can detect the presence of this field distortion. Please describe your method in this case with enough details. (Hint: Consider where you can get an image to replace the CT volume using only the equipment at hand.)
    c. Please extend the detection algorithm to show that one can determine the amount $\Delta B$ of the field distortion presented in the B readings. (Hint: In this problem you still have access to the undistorted ultrasound calibration transformation X, such that if p_u is a point in an ultrasound image, then the point relative to the ultrasound tracker body is given by X*p_u.)

3. As presented in the lecture, we solve AX=XB when we have corresponding A's and B's motions (A = $[R_A, \vec{p}_A]$, and B= $[R_B, \vec{p}_B]$). Ideally, we need to acquire pairs of A's and B's with sufficient motion to accurately measure the unknown frame X. Here we like to examine the ability to solve AX=XB with special and limited motions:
    a. Assume we have pure translation, i.e. $R_A = R_B = I$. Please find which part of X can be recovered and how?
    b. Explain how you would determine if the orientation of the probe does not change during scanning?

c. From (a) and (b), describe a method to detect variations in the calibration frame X during scanning as a real-time quality control.

d. Suppose that you only have a 2D ultrasound probe. In some cases, it may be possible to detect variations in the calibration frame X during scanning. Explain what motions will permit this check and how you would perform it.