ENME489C/ENME808M: Problem Set 9
Camera Calibration

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1 Problem Statement

In this problem set, your goal is to find and accurately locate targets with a camera. You will estimate the metric position of the centroids of the fiducials from problem set# 7, w.r.t the camera reference frame. For this, we will first calibrate a webcam [Logitech c270]. Camera Calibration is the process of estimating the intrinsic parameters of a camera. In other words we want to estimate the focal length, principal point and lens distortion co-efficients of the camera. This link and this link provides a good explanation of the parameters we want to estimate. After obtaining the camera parameters you will segment the MRI fiducials and use the calibration parameters that you just found to estimate the fiducial positions in the Camera Reference Frame. **NOTE** that this problem set is a group exercise. You are expected to work in a group of three for this problem set. You will only need to submit one solution set per group and all group members will be graded equally.

There are following parts to this Problem Set:

- Camera Setup & MRI fiducials segmentation(30 pts)
- Webcam calibration(20 pts)
- Estimating the position [X,Y] of the fiducials in the camera Reference Frame & Validation (30 pts)
- Estimating the depth to the fiducials from a single view from the know geometry of fiducial frame [MUST for Grad Students and OPTIONAL for undergrad students](20 pts)
- Report (20 pts)

For this problem set you will need the following (components 5-8 are provided to you):

1. Your Laptop/PC with MATLAB2017a with access to a printer

2. "MATLAB support package for USB webcams". This can be installed from Add-ons>Get Hardware Support Packages within MATLAB

3. "Camera Calibration Toolbox". This can be downloaded from here. More information about this toolbox is here. Download the .zip file, extract the folder and add the folder to the MATLAB path. This toolbox consist of standalone MATLAB files for performing camera calibration.

4. Your assembled stages from problem set 2.

5. Logitech c270 webcamera

6. 3D printed model of Marker Frame, Targets and Mount

7. MRI Marker fluid filled fiducials [3 Nos]

8. Additional mounting hardware for camera and Marker Frame

9. Some brown tape/double sided tape

camera_calib.m is the main file for this problem set where you will enter different parameters as per your setup. You have to complete two files in **compute_marker_location.m** and **pixel_to_world.m**. camera_calib.m will call your implementation in these functions.

2 Experimental Setup

2.1 Fiducial and Target Bracket Assembly

You will insert your MRI fiducials in the circular slots that are present in the provided frame and fix the fiducials with glue. You might have to clean the provided 3D printed parts with a file to mount the fiducial and target bracket into the stand. Figure 1 shows you this assembly. Then, you will mount the fiducials and target on one of the aluminium beams (using the stand) and mount this beam to the base of one of the linear stages using a T-plate [provided with this problem set]. **NOTE**: You might want to disassemble one of your linear stages from the first lab to get the aluminium beams, corner brackets and fasteners for mounting the camera and the fiducial frame [We will need only two of your assembled linear stages for the final project]. Specifically, you will need one beam for mounting the MRI fiducial frame and target rings. You can choose the 150 mm beam for this.

2.2 Camera Setup

You can mount your camera as it is shown in figure 2. You may use brown tape or double sided tape to fasten the camera to one of the beams and use two other beams along with a T-bracket [provided with this lab] to mount the camera as shown in figure 2. By mounting the camera in this fashion, you can move your camera using the horizontal beam and position it such that fiducials are visible in the camera's field of view. See figure 3 for a picture of the setup.

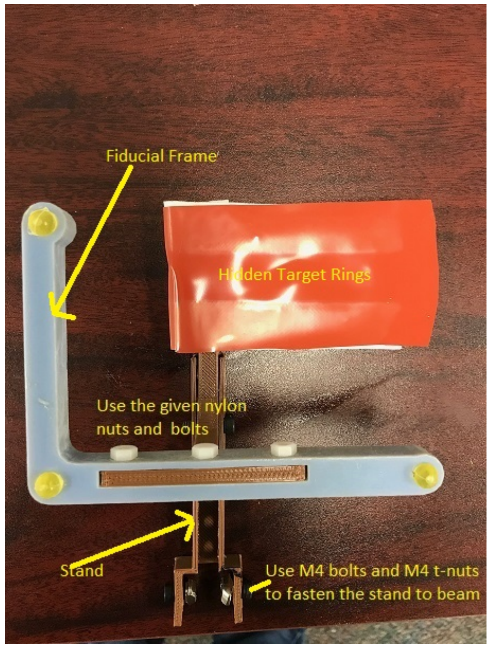

Figure 1: Picture of the fiducial and target bracket. Peel of the fiducials from the strip you are provided and glue it in the slots. Use the provided M4x16 bolt and nut to fasten the target rings to the stand. Use the provided M4 bolts and T-nuts to fasten the stand to a 150 mm beam

Make sure the camera axis [Z-axis] is parallel to the ground and the camera X-Y plane is perpendicular to the ground. By enforcing this constraint, we simply the robot camera calibration later on in the final project.

3 Webcam Calibration

Once your setup is ready, you should calibrate the camera using the instructions mentioned here. The link shows you the way to setup the calibration rig. You will have to print a checkerboard pattern and click on 15-20 pictures using the provided webcam of the checkerboard at different positions and orientations [yaw, pitch, roll]. For good calibration results, temporarily remove the fiducial and target bracket and place the checkerboard in the general area of the fiducials. For commands to access the webcam and use it from MATLAB check this page. Basically, you will need to use commands like "preview" and "snapshot". Then, for calibration you will use the instructions mentioned in the documentation of the toolbox at the first_example section. You should read the entire page for reference. However, you will need to complete only a few of the steps to calibrate your camera and to get your camera intrinsics:

calib_gui>standard>Read Images>Extract Grid Corners>Calibration>Recomp. Corners>Calibration>save

The commands should be run from the same folder where the calibration images are stored. You should refer to the documentation for understanding how to pick the grid corners.

Figure 2: Picture of camera stand. You can use two 205 mm beams and one 187 beam to get this kind of setup. Use five M5 bolts and T-nuts that you used for mounting your bearings for the T-plate. Also, you may use one of the corner brackets and two of the brackets that you machined in Problem Set 2. One other 150 mm beam that you have will be used in final project to assemble the end-effector

Once, the calibration is performed, we will have our calibrated intrinsic matrix stored in the variable "KK". You will use this matrix for your next exercise.

You should try to reduce the pixel error by increasing the corner window size or by adding better images and suppressing images with lots of pixel error. As a reference, reprojection errors < 1 pixel are considered ok. You can also try using the 'Analyse' option in the calib_gui to isolate problematic images as mentioned in the documentation.

Place the checkerboard in contact with the fiducials (should be perpendicular to ground) for at least one of the calibration images and compute the extrinsics using 'Comp. Extrinsic' option in calib_gui on this image. You will need this value to estimate the Z distance of the fiducials in the camera frame in later sections. You should also compare the computed Z distance with a ruler measurement between camera and fiducial plane. Please add this comparison in your report.

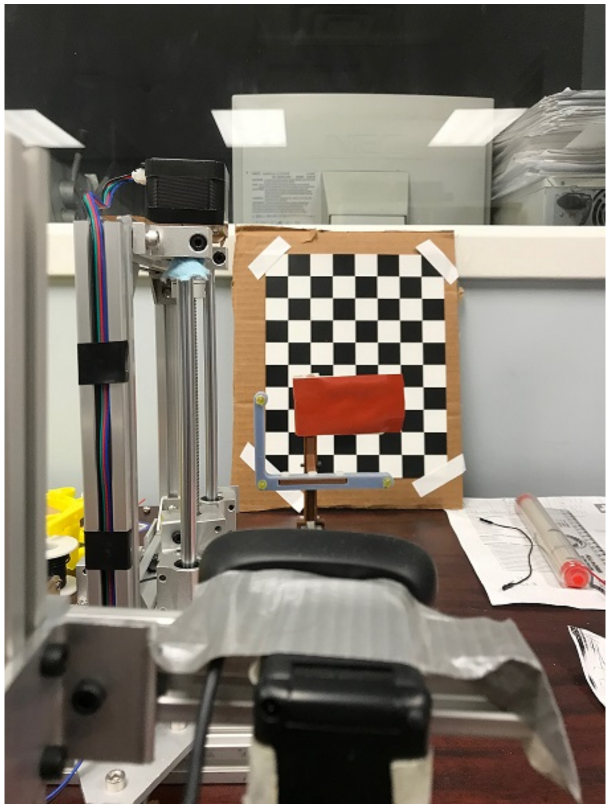

Figure 3: Picture of the experimental setup. Mount the stand holding the target rings on the 150 mm beam and mount this beam using the other T-plate to the base. Use the other five M5 bolts and T-nuts that you used for mounting your bearings for the T-plate. You may choose to mount your other linear stage on the base stage in this problem set itself to adjust the field of view of camera.

4 MRI Fiducials Segmentation

After your setup is ready, you should write a MATLAB function [compute_marker_location.m] that takes image from the webcam as an input and returns the centroid of the location of the fiducials in pixel co-ordinates. Also, you should plot the centroids and contours around the fiducials and include it in your report. We will rely on color segmentation and binary image processing tools from image processing toolbox to segment the fiducials. You should try different color spaces like **HSV** and **LAB** to obtain a more robust performance with segmentation. You can obtain a binary image using image thresholding and by observing the threshold values through `imtool`. You will find the following commands useful for this section:

- `medfilt2`: For image cleaning before processing
- `bwareaopen`: `strel`, `imopen`, `imclose`: For Morphological cleaning.
- `regionprops`, `bwlabel`: For querying properties of blobs in binary images
- `bwboundaries`, `bwperim`: For plotting the contour across the marker

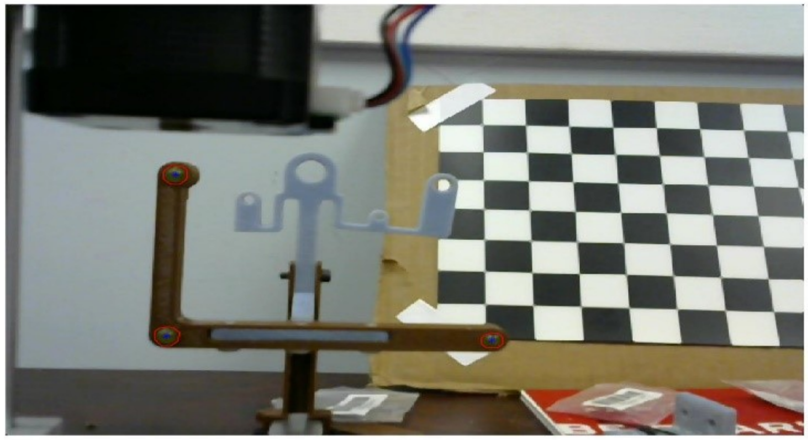

Figure 4: Sample output

Please note that the above list is not exhaustive in any sense and you could discover and may use other functions too. The final result should look something like as shown in figure 4.

5 Estimating position of the fiducials in Camera Reference Frame

In this last part you will write a MATLAB function [pixel_to_camera_frame.m] that computes metric X,Y,Z coordinates of the fiducial markers. You will first need to estimate the Z distance of the fiducials to the camera, using the extrinsics of the checkerboard image when placed touching the fiducial markers in the calibration section. Use this Z value to find X and Y coordinates of the fiducial markers. Compare distances between fiducials to the CAD drawing in problem set 8. You should experiment with at least five different X-Y positions of the markers. How much is this error? Is it constant? Report your findings in the report.

6 For Grad Students

In this section you will evaluate the ability of the single camera to estimate changes in distances. Use the constant X and Y distances between markers to compute the Z distance of the markers in the camera frame. Move the fiducials along Z (at least 5 times) and compare your change in Z estimates to ruler measurements. Calculate and plot the error over change in distance. Report your findings in the report.

7 Submission

A single .zip file with following contents:

- The three MATLAB files.
- A report detailing the steps you took to segment the fiducials and the pertaining equations used for position estimation
- A snapshot of your result with contours and centroids on all the three fiducials clearly highlighted. You may put this in your report.
- Grad students also need to include their findings with plot and the matlab function to estimate change in distance.