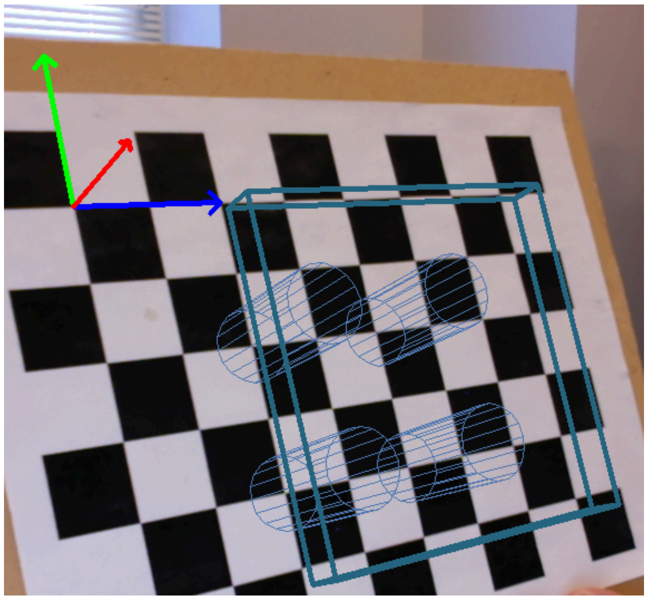
Project 4: Calibration and Augmented Reality

- Due Mar 13 by 11:59pm
- Points 0



Overview

This project is about learning how to calibrate a camera and then use the calibration to generate virtual objects in a scene. The end result should be a program that can detect a target and then place a virtual object in the scene relative to the target that moves and orients itself correctly given motion of the camera or target.

Setup

It's easiest to start by using this image **checkerboard.png (https://northeastern.instructure.com/courses/206145/files/31639254?wrap=1)** as a target. You can display it on a screen, such as a tablet or cell phone, or print it out on paper. If you print it out, it's best to glue or tape it to something flat, like a board or a notebook. This checkerboard pattern, when viewed with the long axis horizontally, has 9 columns and 6 rows of internal corners. You will want to use a pattern like this for both the calibration and VR parts of this project. When creating a coordinate system, it is easiest to consider the squares as being 1 x 1 and define any virtual objects using those units. There are alternative patterns available, such as the **ARuco (https://docs.opencv.org/4.x/d5/dae/tutorial_aruco_detection.html)** toolkit, that will also work and may be more stable.

Tasks

1. **Detect and Extract Target Corners**

   The first task is to build a system for detecting a target and extracting target corners. Get this working cleanly before you move on to the calibration task.

   The calibration documentation (https://docs.opencv.org/master/d4/d94/tutorial_camera_calibration.html) for OpenCV is fairly good. The relevant functions for the first task are findChessboardCorners (https://docs.opencv.org/3.4/d9/d0c/group__calib3d.html#ga93efa9b0aa890de240ca32b11253dd4a) , cornerSubPix (https://docs.opencv.org/4.x/dd/d1a/group__imgproc__feature.html#ga354e0d7c86d0d9da75de9b9701 , and drawChessboardCorners (https://docs.opencv.org/3.4/d9/d0c/group__calib3d.html#ga6a10b0bb120c4907e5eabbcd22319022) . If you use the ARuco markers, the relevant functions are detectMarkers (https://docs.opencv.org/4.x/d2/d1a/classcv_1_1aruco_1_1ArucoDetector.html#a0c1d14251bf1cbb062 and drawDetectedMarkerCorners (https://docs.opencv.org/4.x/de/d67/group__objdetect__aruco.html#ga2ad34b0f277edebb6a132d3069e .

   For the corners argument of findChessboardCorners, I suggest using a std::vector of Point2f type. If you have the definition:

   ```
   std::vector<cv::Point2f> corner_set;
   ```

   Then the number of corners is given by corner_set.size(), and the corner coordinates for the ith entry in the vector are corner_set[i].x and corner_set[i].y. The ARuco detectMarkers function will detect multiple markers, so it requires a std::vector of std::vector of Point2f type.

   Have your video draw the target corners when it finds them. It can also be helpful to print out how many corners it finds, along with the coordinates of the first corner. Note that the first corner of the checkerboard will generally be in the upper left of the pattern as viewed in the image. One benefit of using the ARuco markers is that they are not symmetric and, therefore, will attach the same points to the same locations on the target regardless of orientation.

   Indicate in your report which type of target you are using. Describe any limitations or challenges the system has in locating the target.

2. **Select Calibration Images**

   The next step is to let the user specify that a particular image should be used for the calibration and save the corner locations and the corresponding 3D world points. For example, if the user types 's', then store the vector of corners found by the last successful target detection into a corner_list. You may want to save the most recent image and target corners in variables, as the user may press 's' on an image where the chessboard is not actually found.

Whenever you save a list of found corners, create a std::vector point_set that specifies the 3D positions of the corners in world coordinates. The point_set of 3D world positions will always be the same, regardless of target orientation; the world coordinates are attached to the target. You probably want to use the following definitions for the corner_list, point_set, and point_list.

```
        std::vector<cv::Vec3f> point_set;
        std::vector<std::vector<cv::Vec3f> > point_list;
        std::vector<std::vector<cv::Point2f> > corner_list;
```

To build the 3D world point set you can either try to get specific and figure out the size of a target square in mm, or you can just measure the world in units of target squares. For the chessboard, you would give the corners coordinates of (0, 0, 0), (1, 0, 0), (2, 0, 0), and so on. Note that if the (0, 0, 0) point is in the upper left corner, then the first point on the next row will be (0, -1, 0) if the Z-axis comes towards the viewer.

There need to be as many points in the 3D world point_set as there are corners in the corner_set. You also need as many point_sets in the point_list as there are corner_sets in the corner_list. Note, the most common mistake when working with the chessboard target is swapping the number of rows and columns on the point_set.

You may want to store the images themselves that are being used for a calibration. **Include a calibration image with chessboard/marker features highlighted in your project report.**

3. **Calibrate the Camera**

   If the user has selected enough calibration frames--require the user to select at least 5--then let the user run a calibration. Alternatively, you could continuously update the calibration each time the user adds a new calibration image (beyond some minimum number), telling the user the current per pixel error after each calibration.

   Use the cv::**calibrateCamera** **(https://docs.opencv.org/3.4/d9/d0c/group__calib3d.html#ga3207604e4b1a1758aa66acb6ed5aa65d)** function to generate the calibration. The parameters to the function are the point_list, corner_list (definitions above), the size of the calibration images, the camera_matrix, the distortion_coefficients, the rotations, and the translations. The function also has arguments for information about how well each parameter was estimated. You may want to use the flag CV_CALIB_FIX_ASPECT_RATIO, which specifies that the pixels are assumed to be square (not a bad assumption these days). Radial distortion is optional, and you may want to have it turned off at first. For cell phone cameras, though, it may be necessary to model radial distortion to get a sufficiently low reprojection error.

The number of distortion parameters estimated by the system is determined by the length of the vector of 0s that you pass into the function for the distortion coefficients argument. To skip radial distortion, pass in a std::vector<double> of zero length.

You will have already generated the point_list and corner_list vectors. Make the camera_matrix a 3x3 cv::Mat of type CV_64FC1. The 64F type is a **double**. If you define it or access it as a <float>, it will not work. Initialize the 3x3 camera_matrix to something like.

```
[1, 0, frame.cols/2]
[0, 1, frame.rows/2]
[0, 0, 1           ]
```

Print out the camera matrix and distortion coefficients before and after the calibration, along with the final re-projection error. The two focal lengths should be the same value, and the u0, v0 values should be close to the initial estimates of the center of the image. Your error should be less than a pixel (< 1), if everything is working well. For large images or cell phone images, the per-pixel error may be more like 2-3 pixels. **Include the error estimate in your report.**

The calibrateCamera function also returns the rotations and translations associated with each calibration image. If you saved the calibration images, you might want to also save these rotations and translations with them. OpenCV provides a useful function for visualizing the camera locations relative to the target.

Enable the user to write out the intrinsic parameters to a file: both the camera_matrix and the distortion_ceofficients. **Include your calibration matrix in your report, along with the corresponding re-projection error.**

4. **Calculate Current Position of the Camera**

   For the remaining tasks you can write a completely separate program or continue to enhance your original one.

   Write a program that reads the camera calibration parameters from a file and then starts a video loop. For each frame, it tries to detect a target. If found, it grabs the locations of the corners, and then uses **solvePNP (https://docs.opencv.org/3.4/d9/d0c/group__calib3d.html#ga549c2075fac14829ff4a58bc931c033d)** to get the camera's pose (rotation and translation) relative to the target.

   Have your program print out the rotation and translation data in real time, as you are testing this task. **Include in your report a description of how these values change as you move the camera side to side. Do they make sense?**

5. **Project Outside Corners or 3D Axes**

   Given the pose estimated in the prior step, have your program use the **projectPoints (https://docs.opencv.org/3.4/d9/d0c/group__calib3d.html#ga1019495a2c8d1743ed5cc23fa0daff8c)** function to project the 3D points corresponding to at least four corners of the target onto the image plane in real time as the target or camera moves around. Alternatively, put 3D axes on the target attached to the origin. Displaying 3D axes will help you build your virtual object. **Do the reprojected points/axes show up in the right places? Include at least one image from this step in your report.**

6. **Create a Virtual Object**

   Construct a virtual object in 3D world space made out of lines **that floats above the board**. Then project that virtual object to the image and draw the lines in the image. Make sure the object stays in the proper orientation as the camera moves around. You may want to use an asymmetrical virtual object to aid in debugging. Try making something more complex than a cube.

   When designing your object, design it in world space as a set of lines between 3D points (start with 2-3 lines at most and build from there). Transform the endpoints of each line into image space using the cv::projectPoints function, which uses the rotation matrix, translation matrix, distortion parameters, and calibration matrix. Then draw a line between the two image space points.

   Have fun. **Describe your virtual object and take some screen shots and/or videos of your system in action for your project report.**

7. **Detect Robust Features**

   Pick a feature (e.g. Harris corners or SURF features) and write a separate program that shows where the features are in the image in a video stream. Make a pattern of your choice and show where those features show up on the pattern. Experiment with different thresholds and settings so you get a feel for how the features work. **In your report, explain how you might be able to use those feature points as the basis for putting augmented reality into the image.**

   Take some screen shots and/or videos of the system working.

Extensions

- Especially creative virtual objects and scenes are a good extension. It is possible to integrate

OpenCV with OpenGL to render shaded objects (big extension).
- Get your system working with multiple targets in the scene.
- Test out several different cameras and compare the calibrations and quality of the results.
- Get your AR system working with a target other than the checkerboard, like a photo, painting, or object of your choice that is not a checkerboard. Make it something where it is easy to find 3-4 points on the object and determine which point is which. Place an AR object somewhere in the world relative to the object.
- Enable your system to use static images or pre-captured video sequences with targets and demonstrate inserting virtual objects into the scenes.
- Not only add a virtual object, but also do something to the target to make it not look like a target any more.
- *Uber extension:* Figure out how to get the 3D points on an object in the scene if the scene also has a calibration target. Show the 3-D point cloud.

Report

When you are done with your project, write a short report that demonstrates the functionality of each task. You can write your report in the application of your choice, but you need to submit it **as a pdf** along with your code. Your report should have the following structure. Please **do not include code** in your report.

1. A short description of the overall project in your own words. (200 words or less)
2. Any required images along with a short description of the meaning of the image.
3. A description and example images of any extensions.
4. A short reflection of what you learned.
5. Acknowledgement of any materials or people you consulted for the assignment.

Submission

Submit your code and report to [Gradescope (https://www.gradescope.com)](https://www.gradescope.com). When you are ready to submit, upload your code, report, and a readme file. The readme file should contain the following information.

- Your name and any other group members, if any.
- Links/URLs to any videos you created and want to submit as part of your report.
- What operating system and IDE you used to run and compile your code.
- Instructions for running your executables.

- Instructions for testing any extensions you completed.
- Whether you are using any time travel days and how many.

For project 4, submit your .cpp and .h (.hpp) files, pdf report, and readme.txt (readme.md). Note, if you find any errors or need to update your code, you can resubmit as many times as you wish up until the deadline.

As noted in the syllabus, projects submitted by the deadline can receive full credit for the base project and extensions. (max 30/30). Projects submitted up to a week after the deadline can receive full credit for the base project, but not extensions (max 26/30). You also have eight time travel days you can use during the semester to adjust any deadline, using up to three days on any one assignment (no fractional days). If you want to use your time travel days, note that in your readme file. If you need to make use of the "stuff happens" clause of the syllabus, contact the instructor as soon as possible to make alternative arrangements.

Receiving grades and feedback

After your project has been graded, you can find your grade and feedback on Gradescope. Pay attention to the feedback, because it will probably help you do better on your next assignment.