Department of Electrical and Computer Engineering
University of Illinois at Chicago

ECE 452C | Project 1 | Date: 10/28/2019

Due date: 11/6/2019

One of the most important tasks in robotics is localization, where the robot needs to determine where it is in the environment. In recent years, computer vision has emerged as one of the most successful approaches to localization. In this project you will need to **implement camera pose estimation** algorithm using ArUco library.

Note that each successive project will build on the earlier ones. So make sure you carefully finish all the required tasks, otherwise you will jeopardize your ability to complete future projects.

1 The Task

Given an environment where a number of ArUco markers are located, your goal is to find the configuration of the camera with respect to a global reference frame.

For example, in Figure 1, the configuration of the marker **A** w.r.t. frame **S** is known and equals g_{SA}. The coordinates of the camera are unknown. With the help of ArUco library you can estimate the configuration of a marker in the camera frame **C** denoted by g_{CA}. Using this information, you may also estimate the configuration of the camera frame C w.r.t. reference frame **S**.

1.1 Steps

1. Install Python 3. You may use Anaconda distribution. It is available for all platforms.
2. Install OpenCV. If you are using the Anaconda distribution you may follow this page. If you are using `pip`, install opencv-contrib which includes the ArUco library.

   Once installation is complete, verify that everything works by typing `import cv2.aruco as aruco` in the python3 command line.
3. Read the Documentation of ArUco library. Specifically, read page 12 for *"Estimating pose with marker maps"*.
4. Calibrate your camera. Regular cell phone camera is suitable. You may follow this tutorial. In general, there are many ways to calibrate the camera. All of them are fine, as long as you are getting accurate camera matrices.
5. Prepare the environment:
   (a) Use a workspace of about 2×2 meters.
   (b) Place **three** printed ArUco markers in the area so that at least two of them are visible from a large part of the workspace.

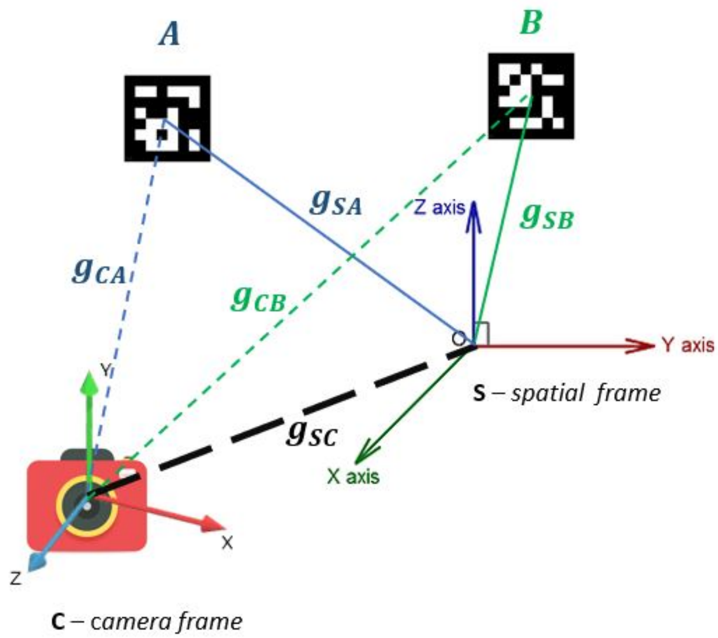

Figure 1: Illustration of the environment

6. **Marker localization:** Select one marker to correspond to the reference coordinate frame **S**. Next take multiple photos with your camera that contain at least 2 markers. In each case, implement camera pose estimation algorithm. To do so, you may follow various tutorials [1, 2, 3 etc] on how to detect and estimate the pose of markers. As a result, you will get the transformation g_{ca} between the camera frame **C** and the marker frame **A**. If there is more than one marker in the photo, say corresponding to frames **A** and **B**, you can find g_{AB}.

7. **Camera (robot) localization:** Take multiple photos by your camera from different spots. While taking pictures record the actual location of the camera. Estimate the camera pose, and given you know the configuration of each marker in frame **S**, compute the configuration of the camera in frame **S**. In each case, report the homogeneous transformation g_{sc}, and then interpret it in terms of the location of the origin of the frame **C**, and the axis and angle of rotation of the frame **C** w.r.t. frame **S**. Finally, compare the output of your algorithm with the actual location/orientation.

2 More about Localization

Localization is an essential functionality for mobile robots. The nature of this problem could vary depending on the application. For example, if the agent is an airplane then localization would mean finding its (x, y, z) coordinates (with respect to a global reference frame) and its orientation (e.g., yaw, pitch and roll angles). In total, localization involves finding 6 parameters that describe a configuration in $SE(3)$.

3 Questions

1. What is the accuracy of your estimation?
2. Do you get better accuracy with more markers in step 7? Compare the localization results derived from an image with only 1 marker, 2 markers and 3 markers by averaging the exponential coordinates.

   Justify with experiment.
3. In step 7, do you get better accuracy if you combine the results from multiple photos taken at the same position?
4. Assume you are given a mobile robot with camera on board in a relatively large environment (i.e. you may not capture marker from every position of the robot). One possible option, you can use the same technique but placing as many markers as possible so that you will detect at least one marker from any instance. However, this will come at higher cost.

   How would you solve this problem? How you will optimize the usage of markers? Elaborate the strategy.

4 Grading

Report: 30%
Questions: 40%
Code: 30%

5 The Report

To submit the report describing your work, follow these steps:

1. Take a video of your robot performing the task. Upload the video to YouTube. The name of the video should read **ECE452C_Fall-2019_Proj-01_Team-##**. Remember to include your team number in the video name.
2. Only **one member** of each group should submit the group report to Blackboard.
   (a) On the first page of the report (cover page) include the **team number** and team members' names, followed by the **link** to your video. On the same page, clearly state how the work was split among team members.
   (b) Explain the difficulties you faced and what steps you took to tune the sensors.
   (c) The report should contain your well-commented code.
3. Upload your code to Blackboard so we can test it on our robot.

Note that all the team members should be involved in all parts of the project. That is, even though you will divide the tasks, all should be aware of the details of various tasks. So, if we ask questions from the part that you were not responsible for, you need to be able to answer.

On Plagiarism

It is important that you thoroughly understand how to work with the robot. Copying the code from another group or other source is therefore not allowed. It will be considered plagiarism, resulting in a failing grade and further possible disciplinary action.