MS5125/MS5145

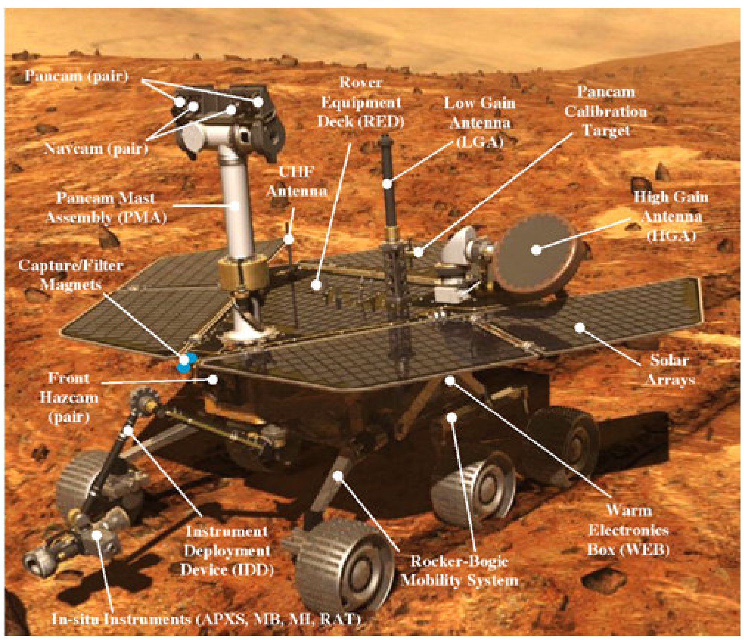
ENGINEERING MATHS 1A

PBL SET

CAMERA CALIBRATION AND USE IN ROBOTIC VISION

INTRODUCTION

NASA sent two robots rovers to Mars in 2004, called Spirit and Opportunity, to study the planet. Today, they are still actively collecting data. Below is photo of one of the two rovers. Notice the number of cameras mounted on the rovers. These cameras act as the rovers' eyes, aiding in its navigation (through the "Navcam") and identification of hazards (through the "Hazcam") amongst other functions.



(Courtesy of NASA/JPL-Caltech - http://marsrovers.nasa.gov/home/)

Therefore cameras are a critical component of the rovers in order to process the visual data. However, in order for the cameras to be useful to the rovers, they have to be calibrated, which is why the rovers are fitted with calibration target ("Pancam calibration target"). But what exactly is meant by calibration?

Camera calibration is defined by Tsai (1987) as "the process of determining the internal camera geometric and optical characteristics and/or the 3D position and orientation of the camera frame relative to a certain world coordinate system". In this PBL problem, the camera calibration that is of interest is that of the 3D position and orientation of the camera frame. Therefore, several questions are posed and a scaled down version of the problem the actual scientists creating the rovers faced is given in this PBL.

QUESTIONS

Our main interest is to answer the following question:

How do the scientists calibrate the cameras on the rovers to enable the rovers to use the information obtained for robot vehicle guidance and for the scientists back on Earth to reconstruct the movements of the rovers?

In order to answer the above question, let us put ourselves into the shoes of these scientists. We have to question ourselves on the following:

1. How do we present the relationship between the position of the camera and the location of the calibration target in matrix format? What type of geometric transformation relays this information?

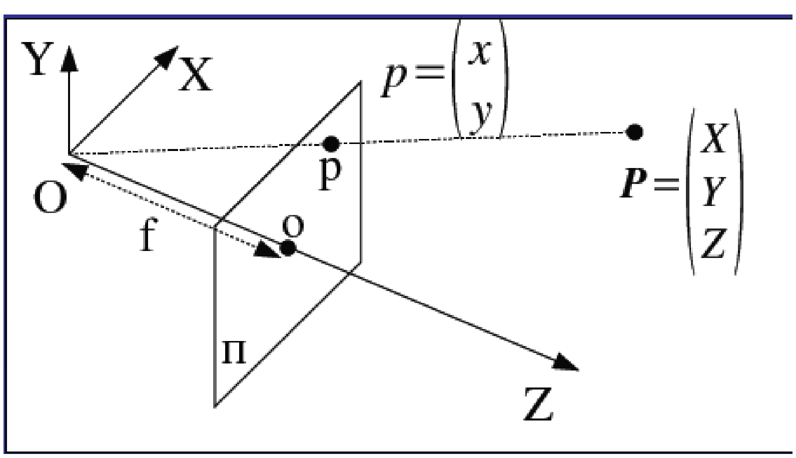
2. What is a frame of reference? How can we relate two different frames of reference, for example, the camera's frame of reference and the real world frame of reference? How is this related to the geometric transformation in Question 1?

3. The images obtained by the cameras are in 2D format while the objects they capture are 3D objects. Describe and discuss at least one projection method that is used in capturing these images.

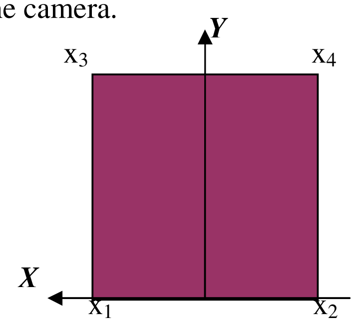
CAMERA CALIBRATION PROBLEM

To better understand the calibration process, let us work on a small problem related to calibration:

Using one of its cameras, the rover sees a 3D cube with an edge of length 10 cm, which is 50 cm directly in front of the rover's camera on the floor of the laboratory. Assume the camera is on the floor and has no height. A representation of the camera and cube positions is shown below where ***P*** is a corner of the cube and ***p*** is its projection to the 2D camera image. Note that ***Y*** represents the height from the floor while ***Z*** here represents the distance of the cube from the camera.



Therefore the image the camera captures will just be as follows, i.e. only one face of the cube is captured by the camera.



- Construct the 3D points of the cube. For example, the bottom left corner of the cube could be represented by the vector (column matrix) $X_1 = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}$ using that corner as the origin of the real world coordinate system. What would be the vectors of the other three corners as shown in the image that the camera can see?

- Knowing the distance of the cube from the rover and the dimensions of the cube, construct either the 4 by 4 homogeneous coordinates geometric transformation matrix or the 3 by 1 geometric transformation vector that describes the relationship between the two locations. This transformation matrix will yield the transformation from the real world coordinate system to the camera's frame of reference.

- What are the coordinates of the 4 corners in the camera's frame of reference?

- The image coordinates of the 4 corners are given as follows:

$$x_1 = \begin{pmatrix} -3.5 \\ 7 \end{pmatrix}, \quad x_2 = \begin{pmatrix} 3.5 \\ 7 \end{pmatrix}, \quad x_3 = \begin{pmatrix} -3.5 \\ 0 \end{pmatrix}, \quad x_4 = \begin{pmatrix} 3.5 \\ 0 \end{pmatrix}$$

  Find the 3 by 3 projection matrix, ***A***, that transforms the 3D coordinates to the above 2D image coordinates. Remember that the projection matrix can be found from

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{1}$$

- Find the 4 by 4 composite matrix that will transform the image coordinates above back to the real world coordinate system.

APPLICATION

Now that we've managed to calibrate our camera to obtain the relationship between the actual object and its camera image, think of at least one other object of different shape and distance from the camera and also think of an appropriate camera image. Apply the matrices to find the image coordinates of the new object. Also demonstrate how it is possible to obtain the real world coordinates of the actual object given the camera image you have created with its set of coordinates based on your earlier results.

Can you now answer the main question of interest?

How do the scientists calibrate the cameras on the rovers to enable the rovers to use the information obtained for robot vehicle guidance and for the scientists back on Earth to reconstruct the movements of the rovers?

References:

R. Y. Tsai, "A versatile camera calibration technique for high-accuracy 3D machine vision metrology using off-the-shelf TV cameras and lenses," IEEE Journal of Robotics and Automation, Vol. RA-3, No.4, August 1987.