Vision based self-localization of a mobile robot in 3D space

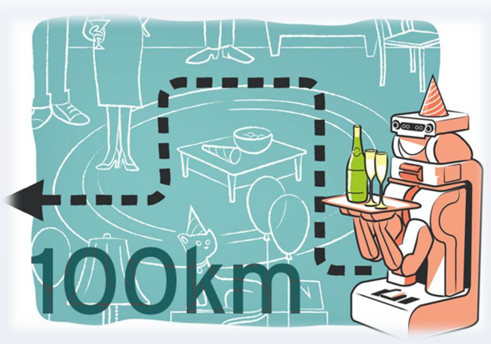
Mohit Chachada[1], Shyh Leh Chen[2]

[1]Department of Mechanical Engineering, Indian Institute of Technology Bombay, India

[2]Profesor, Department of Mechanical Engineering, AIM-HI, National Chung Cheng University, Taiwan

INTRODUCTION

- Navigation of an autonomous robot is one of the most important functions which the robot should be able to perform in order to complete its tasks.
- One way of navigating is to first find out its own location in the environment, using which it can find an optimal path to follow.
- In this project a vision based self-localization system was developed which will be used for robot navigation.



- The vision system developed uses two or more cameras fixed in the robot's working environment at known locations.
- The real time video data is fed to the base computer where the computer vision algorithm in MATLAB calculates the objects location in the 3D space.
- This data is then to be transmitted back to the mobile robot. Thus, knowing its real time position in the working environment, the robot is able to navigate to any desired location.

TASKS PERFORMED BY VISION SYSTEM

- Real-time video streaming from 2 or more cameras fixed at known locations in the environment
- Processing the information to find the pixel location of the vehicle in 2D image
- Transformation of 2D image data to 3D space
- Transmitting the calculated location back to the robot
- Camera calibration

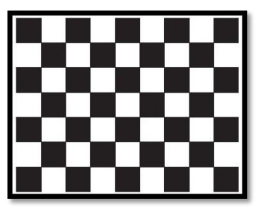
CAMERA CALIBRATION

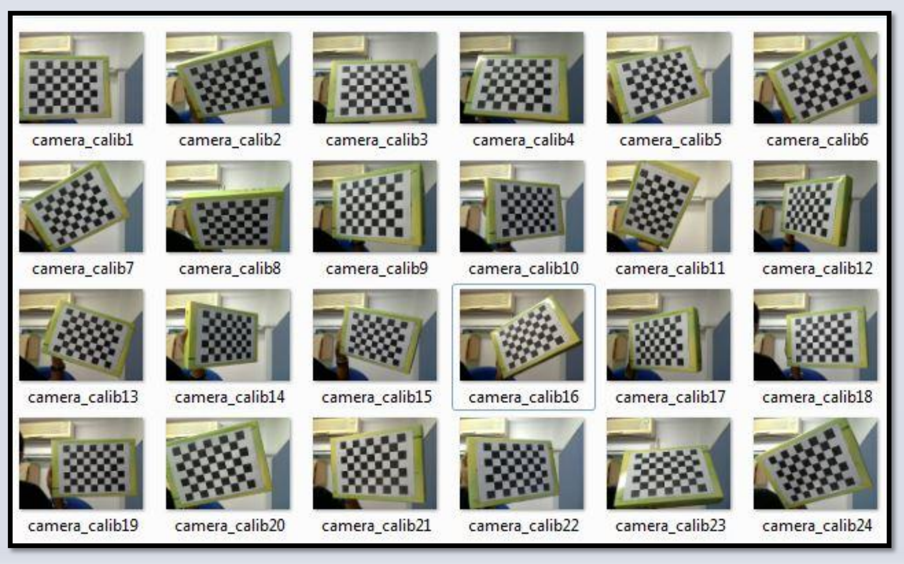
Why is it needed?

- To obtain camera specifications such as focal length (f), pixel length in x and y directions (dx & dy) and principal point pixel coordinates (u_0 & v_0)
- To estimate distortion in camera lens

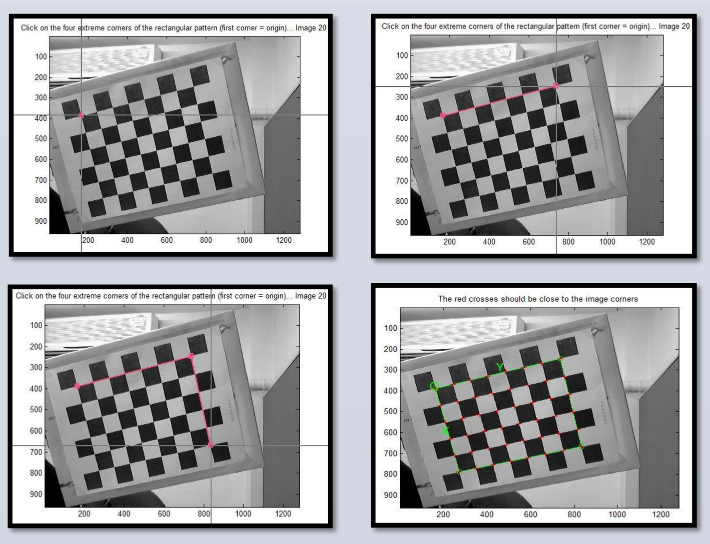
How is it done?

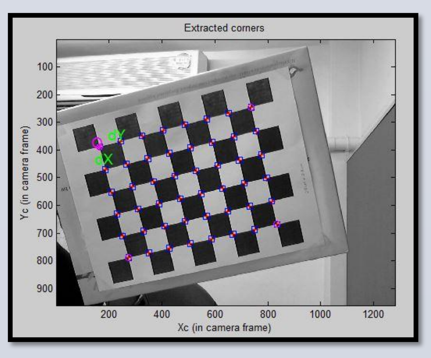
- Using a checker board pattern
- Take images in several orientations
- Extracting grid corners
- Using a camera calibration toolbox for MATLAB





Corner Extraction





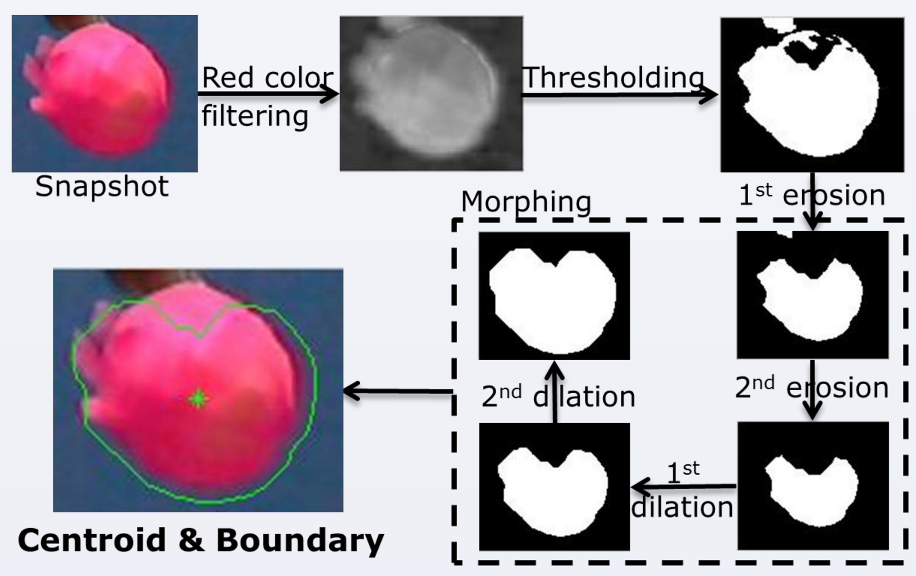
Extracted corners

IMAGE PROCESSING

Small red colored spherical ball (used as a color marker) mounted on the vehicle at known location in vehicle's frame. The task is to track this moving ball in the camera frame and obtain its pixel coordinates.

Video Input → Get snapshot → RGB Image → Red color filter → Grayscale Image → Thresholding → Binary Image → Morphing → Blob Image → Blob finder → Largest Blob → Property finder → Blob boundary and centroid

IMAGE PROCESSING

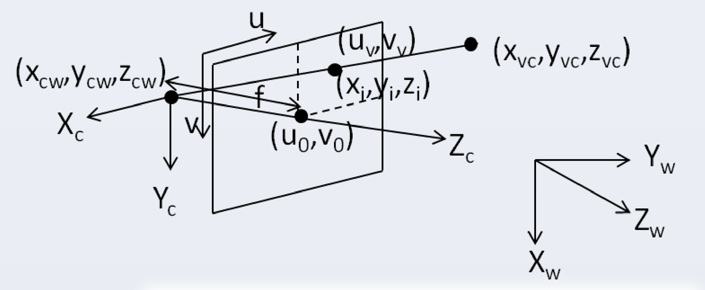


2D TO 3D TRANSFORMATION

Camera Model

$$\begin{pmatrix} x_i \\ y_i \\ z_i \end{pmatrix} = \begin{pmatrix} f & 0 & 0 \\ 0 & f & 0 \\ 0 & 0 & f \end{pmatrix} \begin{pmatrix} \frac{x_{vc}}{z_{vc}} \\ \frac{y_{vc}}{z_{vc}} \\ 1 \end{pmatrix} \quad \& \quad \begin{pmatrix} u_v \\ v_v \end{pmatrix} = \begin{pmatrix} \frac{1}{d_x} & 0 & u_0 \\ 0 & \frac{1}{d_y} & v_0 \end{pmatrix} \begin{pmatrix} x_i \\ y_i \\ 1 \end{pmatrix}$$

$$u_v = \frac{f}{d_x}\frac{x_{vc}}{z_{vc}} + u_0 \quad \& \quad v_v = \frac{f}{d_y}\frac{y_{vc}}{z_{vc}} + v_0$$



Relation between camera frame and global frame

$$\begin{pmatrix} x_{vc} \\ y_{vc} \\ z_{vc} \end{pmatrix} = [R] \begin{pmatrix} x_{vw} - x_{cw} \\ y_{vw} - y_{cw} \\ z_{vw} - z_{cw} \end{pmatrix}$$

Relation between pixel coordinates and global coordinates

$$[A] = \begin{pmatrix} \{(u_{v1}-u_{01})r_{31}-\frac{f_1}{d_{x1}}r_{11}\} & \{(u_{v1}-u_{01})r_{32}-\frac{f_1}{d_{x1}}r_{12}\} & \{(u_{v1}-u_{01})r_{33}-\frac{f_1}{d_{x1}}r_{13}\} \\ \{(v_{v1}-v_{01})r_{31}-\frac{f_1}{d_{y1}}r_{21}\} & \{(v_{v1}-v_{01})r_{32}-\frac{f_1}{d_{y1}}r_{22}\} & \{(v_{v1}-v_{01})r_{33}-\frac{f_1}{d_{y1}}r_{23}\} \\ \{(u_{v2}-u_{02})s_{31}-\frac{f_2}{d_{x2}}s_{11}\} & \{(u_{v2}-u_{02})s_{32}-\frac{f_2}{d_{x2}}s_{12}\} & \{(u_{v2}-u_{02})s_{33}-\frac{f_2}{d_{x2}}s_{13}\} \\ \{(v_{v2}-v_{02})s_{31}-\frac{f_2}{d_{y2}}s_{21}\} & \{(v_{v2}-v_{02})s_{32}-\frac{f_2}{d_{y2}}s_{22}\} & \{(v_{v2}-v_{02})s_{33}-\frac{f_2}{d_{y2}}s_{23}\} \end{pmatrix}$$

$$[B] = \begin{pmatrix} \{(u_{v1}-u_{01})r_{31}-\frac{f_1}{d_{x1}}r_{11}\}x_{cw}+\{(u_{v1}-u_{01})r_{32}-\frac{f_1}{d_{x1}}r_{12}\}y_{cw}+\{(u_{v1}-u_{01})r_{33}-\frac{f_1}{d_{x1}}r_{13}\}z_{cw} \\ \{(v_{v1}-v_{01})r_{31}-\frac{f_1}{d_{y1}}r_{21}\}x_{cw}+\{(v_{v1}-v_{01})r_{32}-\frac{f_1}{d_{y1}}r_{22}\}y_{cw}+\{(v_{v1}-v_{01})r_{33}-\frac{f_1}{d_{y1}}r_{23}\}z_{cw} \\ \{(u_{v2}-u_{02})s_{31}-\frac{f_2}{d_{x2}}s_{11}\}x_{cw}+\{(u_{v2}-u_{02})s_{32}-\frac{f_2}{d_{x2}}s_{12}\}y_{cw}+\{(u_{v2}-u_{02})s_{33}-\frac{f_2}{d_{x2}}s_{13}\}z_{cw} \\ \{(v_{v2}-v_{02})s_{31}-\frac{f_2}{d_{y2}}s_{21}\}x_{cw}+\{(v_{v2}-v_{02})s_{32}-\frac{f_2}{d_{y2}}s_{22}\}y_{cw}+\{(v_{v2}-v_{02})s_{33}-\frac{f_2}{d_{y2}}s_{23}\}z_{cw} \end{pmatrix}$$

[X]: Vehicle's location in 3D space in world frame

$$[X] = \begin{pmatrix} x_{vw} \\ y_{vw} \\ z_{vw} \end{pmatrix}$$

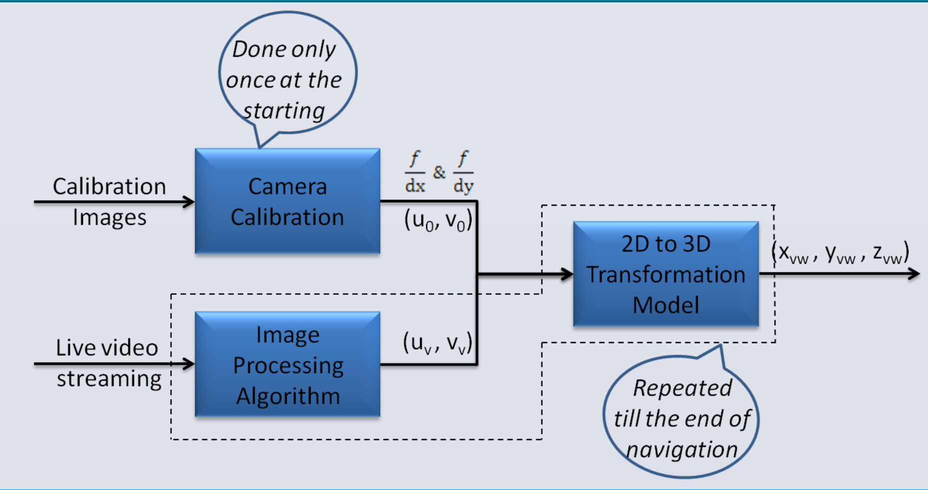
Solve for [X]

$$[A][X] = [B]$$

Least square error solution

$$[X] = (A^T A)^{-1} A^T B$$

OVERALL PROCESS FLOW

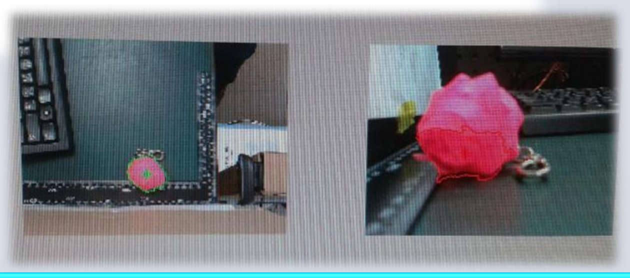


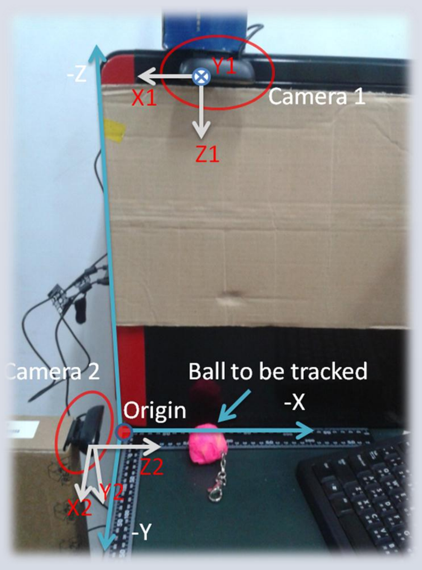
Three main modules: camera calibration, image processing algorithm, and transformation model

EXPERIMENT

- Camera calibration
- 2 cameras mounted in perpendicular views
- Axes are as shown
- Cameras location and rotation matrix are obtained
- Run MATLAB code for image processing and 2D to 3D transformation

Expected: (-100,-30,-25)
Calculated: (-106,-20,-33)
Error: Max 10 mm





CONCLUSIONS

- A vision system is built to perform localization of a robot for its navigation
- Vision system involves processing of a lot of data and thus is not as fast as inertial system but is relatively more accurate
- Use the location calculated from vision system to update the one obtained from inertial system - this integrated system will have the accuracy advantage of vision system and quick response of inertial system

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CONTACT: Mohit Chachada, Email: mohitchachada@iitb.ac.in, Ph: +91-9975762998