EE211: Robotic Perception and Intelligence

Lecture 8 3D Vision for Navigation and Grasping

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Outline

1. Configuration of the Visual System
2. Image Processing

Outline

Number of Cameras

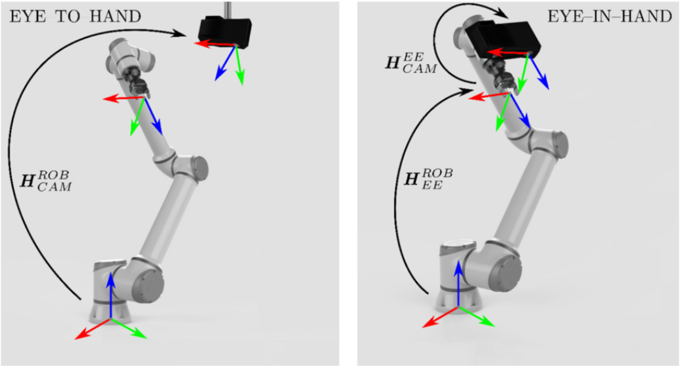
- One, or two or more cameras.
- 3D/Stereo vision: More cameras can retrieve information about depth by evaluating the object's distance with respect to the visual system.
- Humans perceive objects in 3 dimensions $\leftarrow$ the brain receives the same images from two eyes, observing the same scene from slightly different angles.
- One camera can achieve 3D vision: two images of the same object, taken from two different poses.
- With a single image, the depth can be estimated on the basis of certain geometrical characteristics of the object known in advance.
- Mono-camera systems or multi-camera systems: cheaper and easier to calibrate, but lower accuracy.

Robotics: Modeling, Planning and Control.

Placement of Cameras

- For mono-camera systems: fixed or mobile configuration.
- Eye-to-hand (fixed): camera is mounted in a fixed location.
- The camera field of view does not change during the execution of the task $\rightarrow$ the accuracy of such measurements is, in principle, constant.
- Not suitable to high dynamic scenarios, such as assembly.
- Eye-in-hand (mobile): camera is attached to the robot.
- Can be mounted both before and after the wrist.
- When the end-effector is close to the object, the accuracy becomes higher, and occlusions are virtually absent.

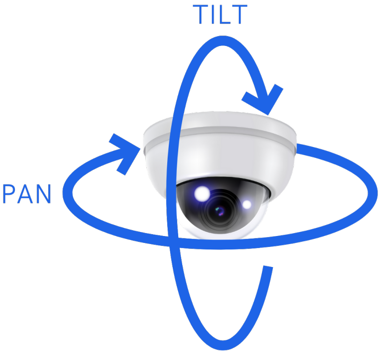
Illustrations



https://blog.zivid.com/importance-of-3d-hand-eye-calibration

Other Examples

- Hybrid configuration system.
- A separate category: robotic heads equipped with a stereo vision system mounted on motorized mechanisms that allow for yaw motion, or pan, and pitch motion, or tilt, hence the name of pan-tilt cameras.

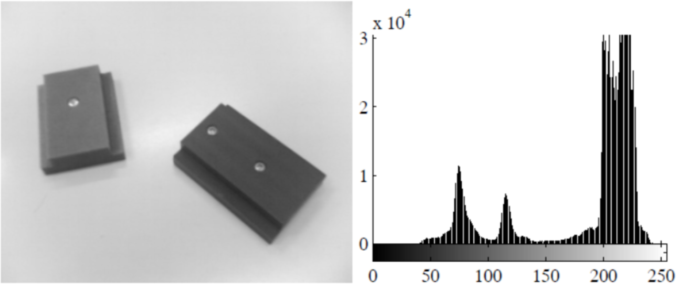


Outline

Image Processing in Robotics

- Very rich and varied and thus requires complex and computational expensive transformations before it can be used for controlling a robotic system.
- Extraction of numerical information from the image, to provide a synthetic and robust description of the objects of interest in the scene, through the so-called image feature parameters.
- Image segmentation: obtain a representation suitable for the identification of measurable features of the image.
- Image interpretation: measurement of the feature parameters of the image.

Example: Gray Levels



- Black-and-white image and corresponding gray-level histogram.
- Gray levels are quantized from 0 to 255.
- Three main peaks — from left to right — corresponding to the darkest object, the lightest object, and the background.

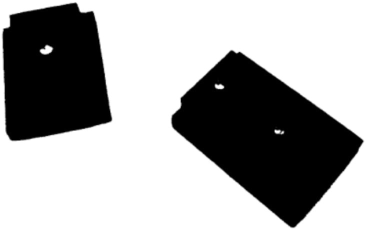
Image Segmentation

- Grouping process: the image is divided into a certain number of groups, referred to as segments.
- Region-based segmentation: grouping sets of pixels sharing common features into two-dimensional connected areas.
- Boundary-based segmentation: identifying the pixels corresponding to object contours and isolating them from the rest of the image.
- Complementary: a boundary can be achieved by isolating the contours of a region and, conversely, a region can be achieved simply by considering the set of pixels contained within a closed boundary.

Region-based Segmentation

- Idea: obtaining connected regions by continuous merging of initially small groups of adjacent pixels into larger ones.
- Binary segmentation or image binarization, separating one or more objects present in the image from the background by comparing the gray level of each pixel with a threshold I.
- Light objects against a dark background, dark objects against a light background.
- Binary image: pixels of objects, set light intensity to 0; pixels of background, set to 1.
- The choice of the threshold.

Region-based Segmentation



- Gray-level histogram: contains clearly distinguishable minimum and maximum values, corresponding to the gray levels of the objects and of the background.
- Dark objects against a light background: the closest minimum to the left, where the threshold $I = 152$.

Boundary-based Segmentation

- Grouping many single local edges, which are sets of pixels where the light intensity changes abruptly: (1) identify local edges; (2) construct short-curve segments by edge linking; (3) obtain the boundaries by joining these curve segments.
- Edge detection is essentially a filtering process and can often be implemented via hardware.
- Boundary detection is a higher level task usually requiring more sophisticated software.
- Using the most effective edge detector to simplify the boundary detection process.

Gradient-based Edge Detection

- Intensity of a pixel: $I(X_I, Y_I)$.
- Gradient of $I(X_I, Y_I)$: measure the rate of change of the gray level, will have large magnitude close to these transitional boundary areas.
- Idea: grouping the pixels where the magnitude of the gradient is greater than a threshold.
- Approximate the derivative along directions X_I and Y_I with the first differences:

$$\Delta_1 = I(X_I + 1, Y_I) - I(X_I, Y_I)$$
$$\Delta_2 = I(X_I, Y_I + 1) - I(X_I, Y_I)$$

Gradient-based Edge Detection

- Roberts operator: the first differences computed along the diagonals of a (2×2) square of pixels.

$$
\begin{aligned}
\Delta_1 &= I(X_I + 1, Y_I + 1) - I(X_I, Y_I) \\
\Delta_2 &= I(X_I, Y_I + 1) - I(X_I + 1, Y_I)
\end{aligned}
$$

- Sobel operator: defined on a (3×3) square of pixels.

$$
\begin{aligned}
\Delta_1 &= I(X_I + 1, Y_I - 1) + 2I(X_I + 1, Y_I) + I(X_I + 1, Y_I + 1) \\
&= -I(X_I - 1, Y_I - 1) - 2I(X_I - 1, Y_I) - I(X_I - 1, Y_I + 1) \\
\Delta_2 &= I(X_I - 1, Y_I + 1) + 2I(X_I, Y_I + 1) + I(X_I + 1, Y_I + 1) \\
&= -I(X_I - 1, Y_I - 1) - 2I(X_I, Y_I - 1) - I(X_I + 1, Y_I - 1)
\end{aligned}
$$

Gradient-based Edge Detection

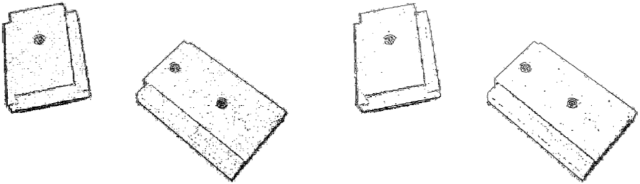
- Approximated magnitude, or norm, of gradient $G(X_I, Y_I)$ can be evaluated using one of the following two expressions:

$$G(X_I, Y_I) = \sqrt{\Delta_1^2 + \Delta_2^2}$$

$$G(X_I, Y_I) = |\Delta_1| + |\Delta_2|$$

- Direction $\theta(X_I, Y_I)$ with the relationship

$$\theta(X_I, Y_I) = \arctan(\Delta_2, \Delta_1)$$



- Contours of image obtained using Roberts (left) and Sobel (right) operators, and binarization.
- thresholds: $l = 0.02$, and $l = 0.0146$.

Image Interpretation

- The process of calculating the image feature parameters from the segments.
- Moments: widely used in visual servoing.
- Definition of moment $m_{i,j}$ of a region $\mathcal{R}$ of an image:

$$m_{i,j} = \sum_{X_I, Y_I \in \mathcal{R}}^{max} I(X_I, Y_I) X_I^i Y_I^j$$

- For binary images, by assuming the light intensity equal to one for all the points of region $\mathcal{R}$, the others are zero, then

$$m_{i,j} = \sum_{X_I, Y_I \in \mathcal{R}}^{max} X_I^i Y_I^j$$

- Moments $m_{0,0}$ coincides with the area of the region, computed in terms of the total number of pixels of region $\mathcal{R}$.

$$m_{i,j} = \sum_{X_I, Y_I \in \mathcal{R}}^{max} X_I^i Y_I^j$$

- Coordinates of the so-called centroid of the region.

$$\overline{x} = \frac{m_{1,0}}{m_{0,0}} \quad \overline{y} = \frac{m_{0,1}}{m_{0,0}}$$

- Central moments:

$$\mu_{i,j} = \sum_{X_I, Y_I \in \mathcal{R}} (X_I - \overline{x})^i (Y_I - \overline{y})^j$$

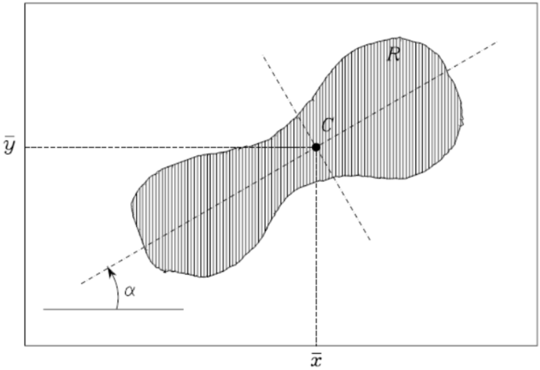
Image Interpretation*

- The central moments of second order $\mu_{2,0}$ and $\mu_{0,2}$ have the meaning of inertia moments with respect to axes X_I and Y_I respectively, while $\mu_{1,1}$ is an inertia product.
- Moment $m_{0,0}$ corresponds to the mass of the body and the centroid corresponds to the centre of mass.

$$\mathcal{I} = \begin{bmatrix} \mu_{2,0} & \mu_{1,1} \\ \mu_{1,1} & \mu_{0,2} \end{bmatrix}$$

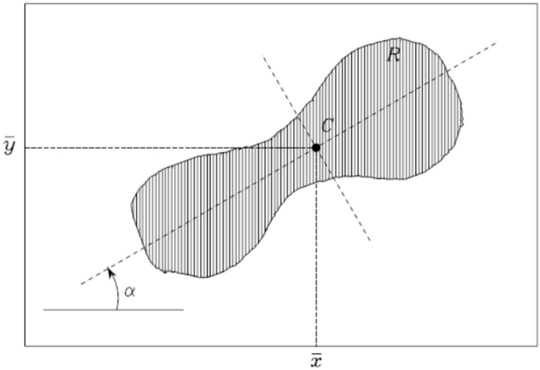
- has the meaning of inertia tensor relative to the centre of mass.

Image Interpretation*



- The eigenvalues of matrix $\mathcal{I}$ define the principal moments of inertia, termed principal moments of the region and the corresponding eigenvectors define the principal axes of inertia, termed principal axes of the region.

Image Interpretation*



- $\mathcal{R}$ is asymmetric $\rightarrow$ principal moments are different $\rightarrow$ characterize the orientation of $\mathcal{R}$:

$$\alpha = \frac{1}{2}\tan^{-1}\frac{2\mu_{1,1}}{\mu_{2,0} - \mu_{0,2}}$$

Q & A

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