A Tutorial on Machine Vision

Prabhas Chongstitvatana
Department of Computer Engineering
Chulalongkorn University
prabhas@chula.ac.th

- Motivation
  - What is Machine Vision
  - Its applications
- Fundamentals
- Specific to Robocup

Fundamentals

Camera model

$1/u + 1/v = 1/f$

u the distance from the lens to the object
v the distance from the lens to the image
f the focal length

M = image size/ object size
f = uM/(M+1)

Example
a 10 cm object, with a camera sensor 8.8 x 6.6 mm., from the distance 0.5 m. find f

M = 8.8/100 = 0.088, f = 500 x 0.088/1.088 = 40.44 mm.

select f = 35 mm.

- image sensor CCD
- video standard NTSC (USA, JAPAN), CCIR (Thailand, Europe)

CCIR
- picture rate 50 Hz (20ms)
- odd/even line (interlace scanning) picture frame rate 25 Hz.
- each frame 625 lines line frequency 625 x 25 = 15625 Hz (64 us)
- 11.5 us for blanking and synchronizing
- 4:3 horizontal-to-vertical aspect ratio

Image Acquisition

sensor sampling frequency
bandwidth of the video signal
A/D sampling frequency (frame grabber)

Sampling

- Spatial frequency components
  - high spatial frequency correspond to quick changes in the image intensity
- Nyquist frequency

Effective resolving power of the image acquisition system

A sensor with 756 sites (along a line) can capture only the signal of spatial frequency 378 Hz

CCIR line frequency is 15625 Hz, the nominal bandwidth 5 MHz, max spatial frequency of video signal is 5 x 10^6 / 15625 = 320 Hz

a frame grabber with sampling rate 512 pixels (in horizontal), can capture only 256 Hz signal.

Aspect ratio

4:3 horizontal-to-vertical
video signal 100:100 --> image 100:75 (frame store)

CCIR 625 lines , only 576 lines are used for visual information
framestore with vertical resolution 512 pixels so
effective aspect ratio 4:(3 x 512/576) = 3:2

the effective pixel distance
vertical 1
horizontal 3/2
diagonal sqrt(13/4)

Digital Image Processing

- **point**
  - contrast streching
  - thresholding
  - noise suppression by image addition
  - background subtraction

- **neighbourhood**
  - convolution
  - noise suppression by averaging
  - low pass filter
  - using median
  - Gaussian smoothing

Gaussing function

G(x,y) = 1/2pi g^2 (exp [-(x^2 + y^2)/2g^2]

where g defines the effective spreading
g = 1.5
G(x,y) = 3,28,135,411,800,1000,800,411,135,28,3

decide max amplitude 1000

thinning, erosion, dilation
(mathematical morphology)

erosion

```
for all pixel
    if pixel is an object AND all its neighbours are objects
        copy it
```

dilation

```
for all pixel
  if pixel is an object
    copy it and its eight neighbour
```

geometric

- spatial warping
  - a spatial transformation
  - an interpolation scheme

(i,j) = (Wx(x,y), Wy(x,y))

Wx(x,y) = sum p sum q a_pq x^p y^q
(for n =2, nine terms)

Wy(x,y) = sum p sum q b_pq x^p y^q
(for n = 2, nine terms)

find a_pq, b_pq

1 Know transformation exactly for a number of points (nine)
2 know x,y and their corresponding i,j
3 to solve the equation of nine unknowns, needs at least nine observations

Grey-scale Interpolation
- nearest-neighbour
- first order interpolation (bi-linear) (4-neighbour)

```
34
12
```

Fit a hyperbolic paraboloid surface defined by the bilinear equation:

f(p,q) = ap + bq + cpq + d

determine a, b, c, d
d = f 1
b = f 2 – f 1
a = f 3 – f 1
c = f 4 + f 1 – f 3 – f 2
example

60,129[12]   61,129 [15]
60,128 [10] 61,128 [14]

What is the grey-value at (60.4, 128.1) ?

f(0.4, 0.1) = (14-10) x 0.4 + (12-10) x 0.1 + (15+10-14-12) x 0.4 x 0.1 + 10
= 11.76

Segmentation

thresholding

T = T(x,y, N(x,y), g(x,y))

if g(x,y) > T   (x,y) is labelled an object

g(x,y) grey-level
N(x,y) neighbour
x,y point co-ordinate

Global, Local, Dynamic
Global threshold

- find threshold by histogram
- bi-modal, multi-modal
- smooth histogram (3x1) averaging operator
- use grey pixels which lie on the boundary

Which pixels are on the boundary?
Use Marr-Hildreth operator to find edges
T = mean of edge pixels

Edge detection

- gradient, difference –based
- template matching

Gradient

the first difference
x-direction: f(x+1,y) – f(x,y)
y-direction: f(x,y+1) – f(x,y)

3 4
1 2

Roberts operator

g(x,y) = sqrt [{f 1 – f 4}^2 + {f 3 – f 2}^2]   RMS of directional differences

g(x,y) = | f 1 – f 4 | + | f 3 – f2 | Absolute

g(x,y) = Max (| f 1 – f 4 | , | f 3 – f2 |)   Rosenfeld and Kak

Combining differencing and local average (to reduce noise) : Sobel , Prewitt

Robert

1	0
0	-1

0	1
-1	0

Sobel

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	0	1

Laplacian

has zero response to gradual change and respond to both sides of edge, once with positive and once with negative sign. An edge is at zero-crossing.

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$$

approx by
L(x,y) = f (x,y) – ¼ { f(x,y+1) + f(x,y-1) + f(x+1,y) + f(x-1,y)}

- Marr-Hildreth 1980
  smooth the image (Gaussian) and isolate zero-crossing (Laplacian)

I(x,y) image
G(x,y) Gaussing

Laplacian of Gaussian

Let D2 be , ∇^2 Py2 be $\frac{\partial^2}{\partial y^2}$

D2{I(x,y) * G(x,y)} = D2 G(x,y) * I(x,y)

2-D convolution can be separable into
four 1-D convolution

D2{I(x,y) * G(x,y)} = G(x) * { I(x,y) * Py2 G(y) } + G(y) * {I(x,y) * Py2 G(x)}

- Template matching

Region growing
- grouping areas with a common feature into region
- What is the criteria for merging two regions?
- At what point does merging cease?

Global thresholding, grey-level

Horowitz and Pavlidis 1976
Quad-tree

Boundary detection: Hough Transform
contour following

Specific to Robocup

- Real-time constraint: Windowing, prediction
- Local threshold
- Colour segmentation
- Shape recognition

3-D machine vision
Visual servoing
Object recognition

Conclusion

Have fun and learn along the way

References

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3. M. Petrou, P. Bosdogianni, Image processing: the fundamentals, John Wiley & Son, 1999. (mathematical foundation of image processing)
4. R. Gonzalez, R. Woods, Digital Image Processing, Addison Wesley, 1992. (the classic of digital image processing)
5. There are plenty of image processing code at www.intel.com