Cameras, Images, and Low-Level Robot Vision

RSS Technical Lecture 5

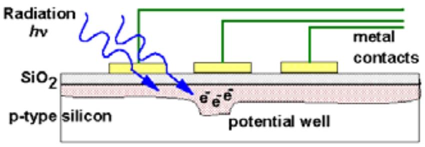
Friday, 17 Feb 2012

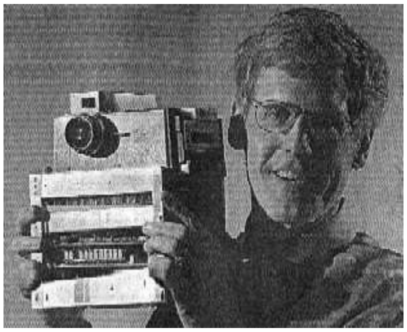
Prof. Teller

Siegwart and Nourbakhsh § 4.1.8

Digital Camera Precursors

- Basis: photoelectric effect (Hertz 1887; Einstein 1905)
  - As light *frequency* increases?
  - As light *intensity* increases?
- Also: advent of CCDs as shift registers (late 1960's)
- First electronic CCD still-image camera (1975):
  - Fairchild CCD element
  - Resolution: 100 x 100 x 1-bit b&w … a whopping *0.1 Megapixels !*
  - Image capture time: *23 seconds*, mostly writing to cassette tape
  - And another 23 seconds to display to a nearby television
  - Total weight: 8-1/2 pounds





Kodak, c. 1975

Kodak

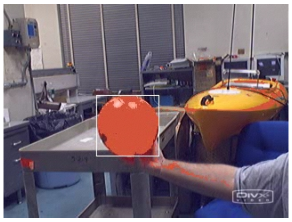
Miniaturization, price point

- In 2012, forty dollars buys a camera with:
  - 1280 x 720 pixel resolution at 30Hz
  - 24-bit RGB pixels (8 bits per channel)
  - Automatic gain control, white balancing
  - On-chip lossy compression algorithms
  - Uncompressed image capture if desired
  - Integrated microphone, USB 2 interface
  - Limitations
    - Narrow dynamic range
    - Narrow FOV (field of view)
    - Fixed spatial resolution
    - No actuation or active vision capabilities

Logitech C270

Digital image contents

- Why are pixels represented as “RGB”?
  - Is world made of red, green, and blue “stuff”?



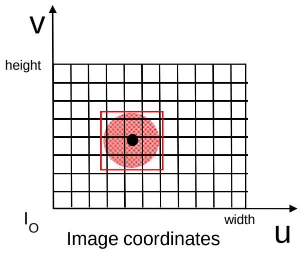
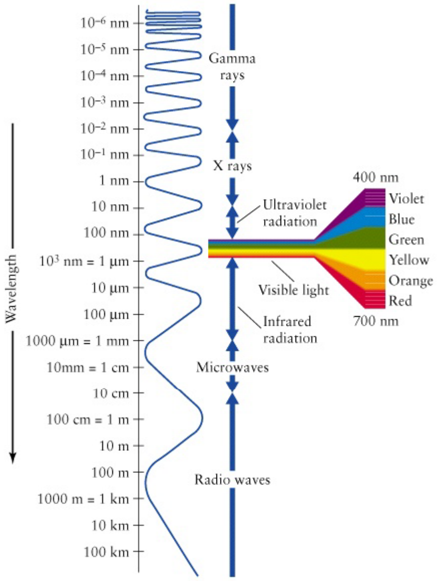


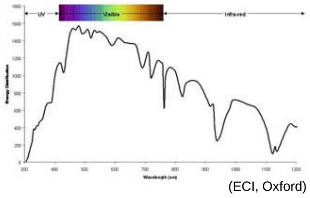
Image coordinates (pixels)

- … Answer requires two brief digressions about human vision & cameras as sensors

Visible light spectrum

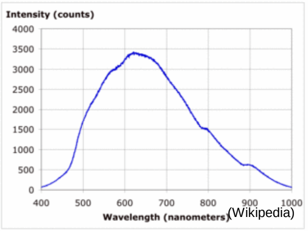


(Freedman & Kaufmann, Universe)



(ECI, Oxford)

Solar spectrum



(Wikipedia)

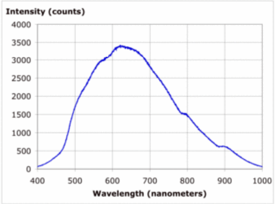
Incandescent spectrum

Image as measurement

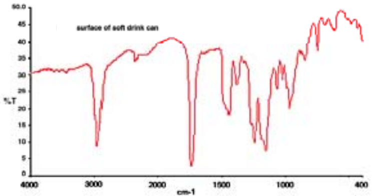
- What does eye/camera actually *observe*?

… the *product* of illumination spectrum
with absorption or reflection spectrum!

= (at each image point)



x



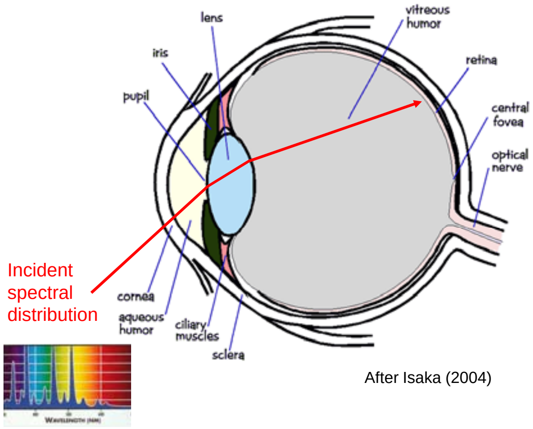
Illumination spectrum

Reflection spectrum (IJVS)

Human eye anatomy

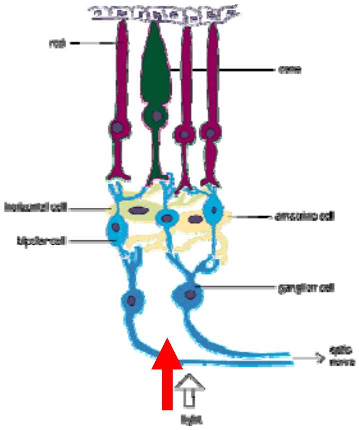
- Spectrum incident on light-sensitive *retina*

(View of R eye from above)



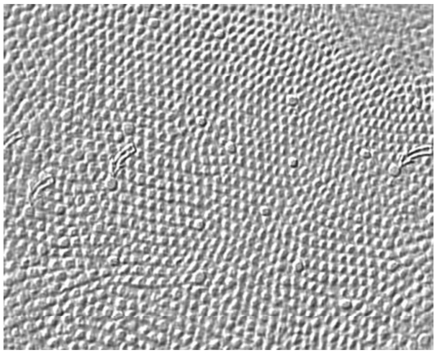
After Isaka (2004)

Rods and cones



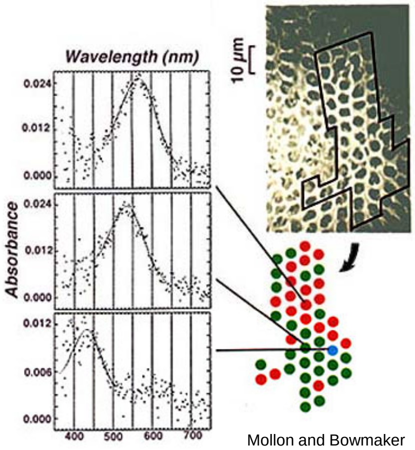
Foveal cone distribution

- Densely packed in fovea, less so in periphery



Visual discrimination of *1 minute of arc* [corresponds roughly to] the center-to-center spacing (3 µm) of the cones of the central mosaic in the foveola (retina.umh.es).

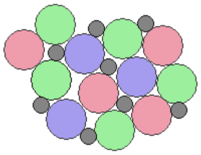
What does “1 minute of arc” mean?



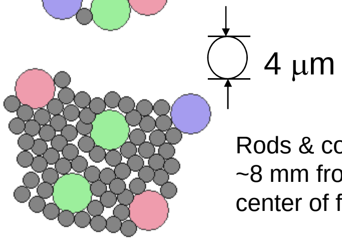
Mollon and Bowmaker

Cone sensitivities

- Three cone types (S, M, and L) are roughly blue, green, and red sensors, respectively. Their peak sensitivities occur at ~430nm, 560nm, and 610nm for an "average" human.

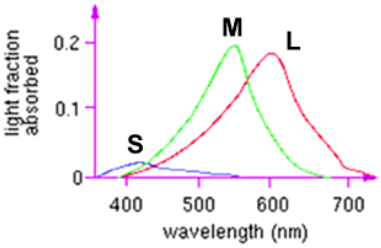


Rods & cones, ~1.35 mm from center of fovea



Rods & cones, ~8 mm from center of fovea

(IJVS)

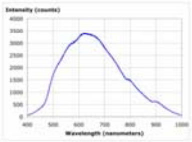


Cone sensitivities as a function of wavelength

Color perception

- The cones form a spectral “basis” for visible light; incident spectral distribution differentially excites S,M,L cones, leading to color vision

= (at each cone site)



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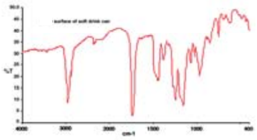
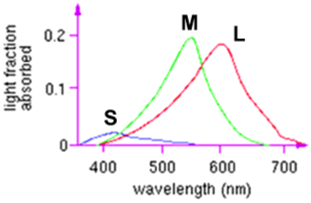


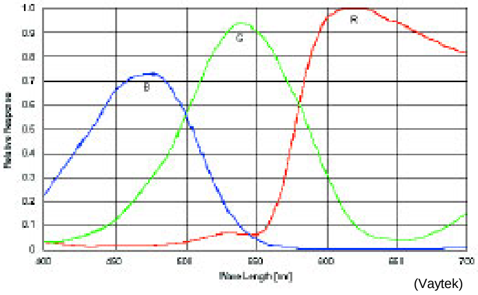
(IJVS)

x



Origin of RGB CCD sensors

- So, in a concrete sense, CCD chips are designed as RGB sensors in order to emulate the human visual system



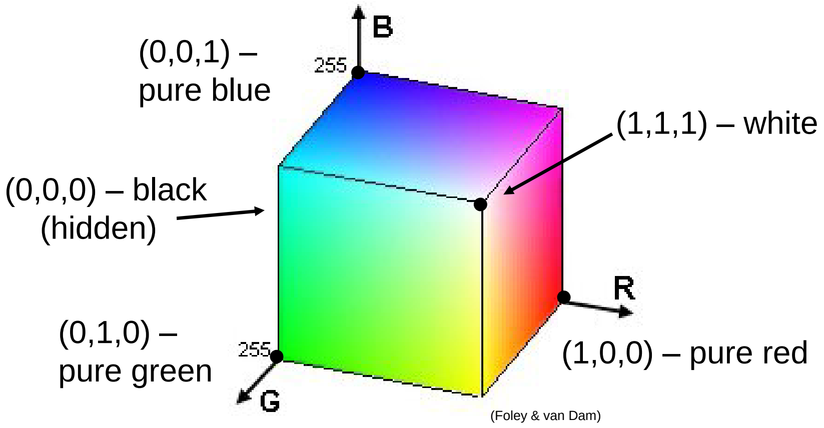
(Vaytek)

CCD with Bayer Filter, Relative Spectral Response Curve

- … End of digressions

RGB Color Model

- Think of R, G, B as a kind of “color orthobasis”



(0,0,1) – pure blue

(1,1,1) – white

(0,0,0) – black (hidden)

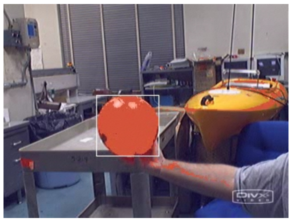
(0,1,0) – pure green

(1,0,0) – pure red

(Foley & van Dam)

Object detection

- Suppose we want to detect an object (e.g., a red ball) in camera’s field of view



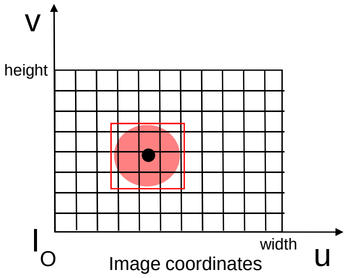


Image coordinates (pixels)

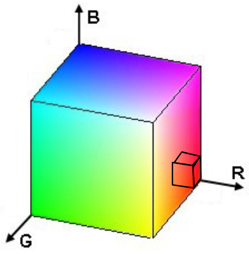
- We simply need to identify all pixels of some specified color in the image … right?

Naïve object detector

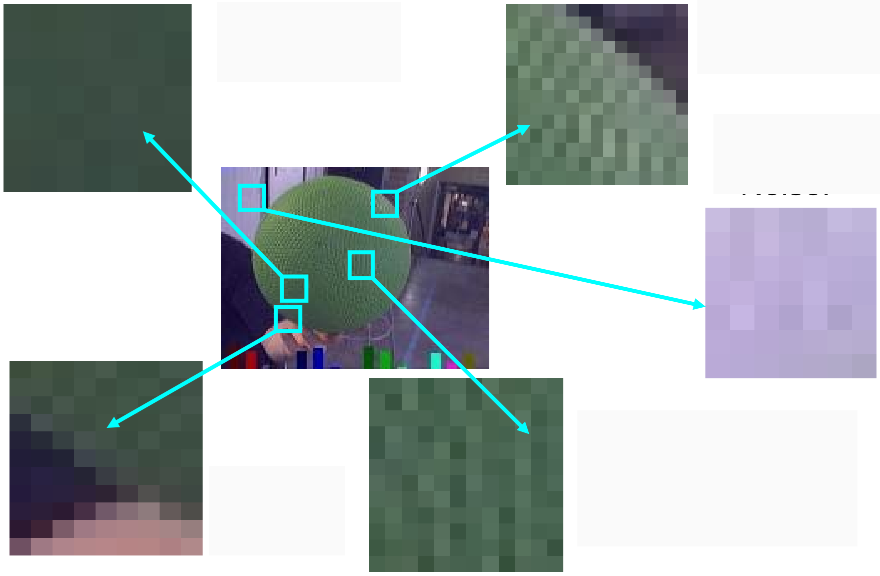
```
set objectPixels = Ø; // empty set

// look for red ball in image
for i = 0 to width-1
   for j = 0 to height-1
      if ( isRed( pixel[i, j] ) ) // classifier
         objectPixels U= {(i, j)};

if ( isBall ( objectPixels ) ) // detector
   // do something in response to ball
```

Pixel classification

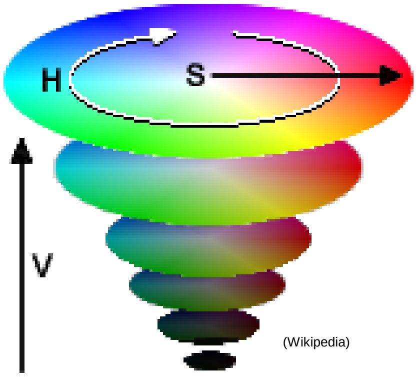
```
Boolean isRed ( pixel p ) {
   if (       p.red >= 0.8      // where do 0.8,
          && p.green < 0.2    // 0.2 come from?
          && p.blue < 0.2 )
      return true;
   else
      return false;
}

// Will this do what we want?
```



Confounding effects: Real-world images



Alternative: HSV Color Model

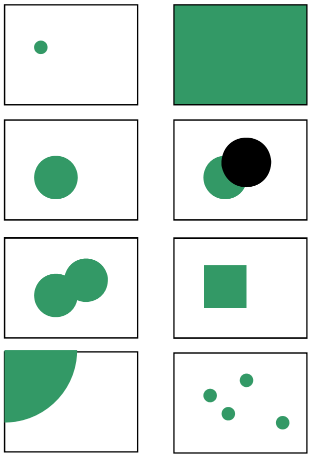


(Wikipedia)

- More robust under illumination changes (why?)
- Still must confront noise, specularity etc.

Naïve object detection

```
Boolean isBall ( set s ) {
  if ( |s| > 0.1 * W * H )  // area threshold
      return true;
  else
      return false;
}

// how might this fail?
```



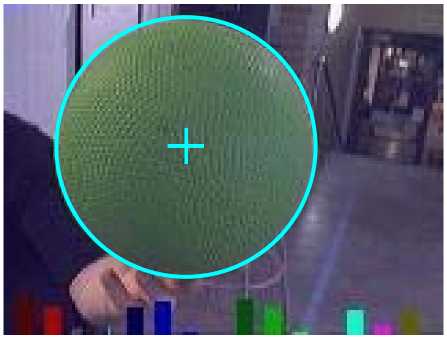
Etc…

(Slightly) improved detection

```
Boolean isBall ( set s ) {
  if ( |s| > 0.1 * W * H  // area threshold
      && s is “ball-shaped” ) {
    return true;
  else
    return false;
}

// how might this fail?
```

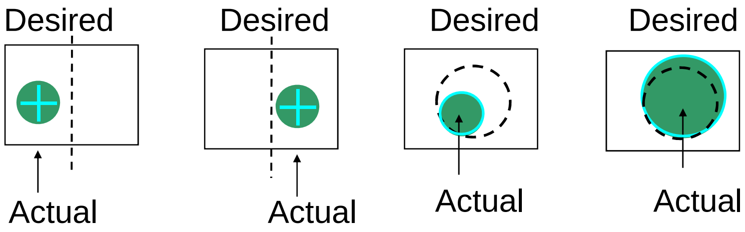
Doing something useful

- Report *presence* of ball in image
  - As function return, message dispatch, etc.
- Estimate *attributes* of (presumed) object
  - Color
  - Size
  - … how?
  - Centroid
  - … how?



- How / when might these estimates be poor?

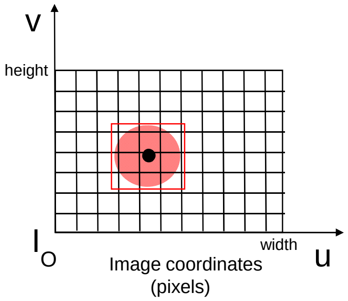
Size, centroid estimation

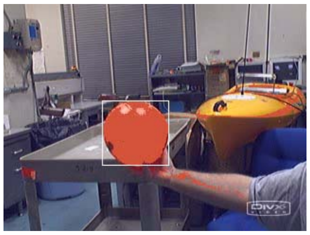


- Can use estimators as inputs to motion controller!
- Suppose we want a 1-meter frontal standoff
  - How do we compute *desired* size in image?
  - Instance of *camera calibration*;
    more examples to come later in term

Application: Visual Servoing (Lab 4)

- Write a “blob detector” in integer (u, v) pixel coordinates
  - Transform pixels from (r,g,b) to chrominance, luminance
  - Given a target hue (e.g., red) and error tolerance, find significant connected components of pixels with that hue
  - Estimate the area and centroid of the largest detected blob
- We will supply several “fiducial objects” (colored balls)
- Issue translation, rotation control so that robot “servos” to the ball, facing it frontally at desired standoff distance





What’s Next in RSS:

- Monday 2/20:
  - Presidents’ Day Holiday: enjoy!
- Tuesday 2/21:
  - Virtual Monday; CI-M Lecture 1: Communication
  - Individual PAR exercises due to CI-M staff
- Wednesday 2/22:
  - CI-M Lecture 2: PARs
  - Lab 2 briefings, wiki materials due
  - Lab 3 (Braitenberg) begins
- Friday 2/24:
  - CI-M Lecture 3: Collaboration
- Monday 2/27 Lecture:
  - ROS (Robot Operating System)