Technical Basis for optical experimentation
Part #4

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Light sensing and recording
Lenses

- **Focus length:**
- **Depth of focus:**
- *f*-numbers or focal ratio: is defined as the ratio of focal distance of the lens and its clear aperture diameter.

<table>
<thead>
<tr>
<th>12 F2.8</th>
<th>14 F5.6 F8 F11</th>
<th>116 F22</th>
</tr>
</thead>
<tbody>
<tr>
<td>wide aperture</td>
<td>small aperture</td>
<td>less light</td>
</tr>
<tr>
<td>more light</td>
<td></td>
<td>larger number</td>
</tr>
</tbody>
</table>
Photo detector

- **Photo detector is a device to convert light to an electric current through photo electric effect.**

- **Quantum efficiency:**
  \[ \eta_d = \frac{N_e}{N_p} \]
  
  - \( N_e \): Number of absorbed photons
  - \( N_p \): Number of emitted electrons

- **Noise:**
  - **Shot noise:** due to random fluctuation of the rate of photon collection and background illumination
  - **Thermal noise:** caused by amplification of current inside the photo detector and by external amplifier.

- **Dark current:** the current produced by the photo detector even in the absence of a desirable light source.

- **Two kinds of photo detectors:**
  - Photomultiplier tubes (PMT)
  - photodiodes (PD) or photo electric cells
**Photo detector**

- **Photomultiplier tubes (PMT)**
  - Photocathode: absorbs photons and emits electrons.
  - Dynodes: increase number of photons
  - Anodes: output
Photo detector

- photodiodes (PD) or photo electric cells
  - P-n junctions of semiconductors, commonly silicon-silicon type.
  - High quantum efficiency
  - But not internal amplification
Linearity and Dynamic Range of a Digital Camera

- **Linearity:**
  - Intensified CCD cameras usually need to check its linearity.

- **Dynamic Range:**
  - The ratio between the full-well capacity and the dark current noise.
  - For example, for a 8-bit CCD camera, maximum intensity is $2^8=256$, dark current noise is about 25, then Dynamic range is about 10.
  
  - Available bits number:
    - 8 bit, 16 bit, 24 bit

\[ y = a + bx + cx^2 + dx^3 \]
\[ a = 1.26, b = 1.05, \]
\[ c = -5.36 \times 10^{-5}, d = -1.67 \times 10^{-9} \]

Input Photon

Gain level 100%
Gain level 90%
Gain level 80%
Gain level 70%
\[ y = x \]
Interlaced Cameras

- The fastest response time of human being for images is about ~ 15Hz.
- Video format:
  - PAL (Phase Alternating Line) format with frame rate of \( f = 25Hz \) (sometimes in 50Hz). Used by U.K., Germany, Spain, Portugal, Italy, China, India, most of Africa, and the Middle East.
  - NTSC format: established by National Television Standards Committee (NTSC) with frame rate of \( f = 30Hz \). Used by U.S., Canada, Mexico, some parts of Central and South America, Japan, Taiwan, and Korea.

Old field (1,3,5...639)  
Even field (2,4,6...640)  

480 pixels by 640 pixels

Interlaced camera

1 frame  
F=30Hz

Odd field  
Even field

16.6ms  
16.6ms

1st field: Odd field  
2nd field: Even field  
One complete frame using interlaced scanning
Progressive scan camera

- All image systems produce a clear image of the background
- Jagged edges from motion with interlaced scan
- Motion blur caused by the lack of resolution in the 2CIF sample
- Only progressive scan makes it possible to identify the driver

Note: In these examples, the cameras have been using the same lens. The car has been driving at 20 km/h (15 mph) using cruise control.
Mystery of flying rods
Digital camera

- **CCD camera** and Intensified CCD (ICCD) camera:
  - Spatial resolution: 1K by 1k, 4K by 4K
  - Frame rate: 30 Hz, High speed camera 1khz ~10K hz
  - In a CCD sensor, every pixel’s charge is transferred through a very limited number of output nodes (often just one) to be converted to voltage, buffered, and sent off-chip as an analog signal. All of the pixel can be devoted to light capture, and the output’s uniformity (a key factor in image quality) is high.

- **CMOS (Complementary metal-oxide semiconductor) cameras**
  - In a CMOS sensor, each pixel has its own charge-to-voltage conversion, and the sensor often also includes amplifiers, noise-correction, and digitization circuits, so that the chip outputs digital bits.
  - These other functions increase the design complexity and reduce the area available for light capture. With each pixel doing its own conversion, uniformity is lower. But the chip can be built to require less off-chip circuitry for basic operation.

- In summary for CMOS cameras:
  - Low cost
  - Operation versatility
  - High speed
  - Quality is not as high as CCD cameras