2D Barcodes and Imaging Scanner Technology

Bradley S. Carlson
2D Barcodes

MaxiCode
- High Speed Sortation
- Invented by UPS
- Used only by UPS

QR Code
- Widely used in Japan
- High Data Content

Data Matrix
- Part marking
- Electronics Industry

Postal Codes
- Postnet
- 4-State

PDF417
- Data files
- Logistics
- Shipping
- Production broadcast
- Identification

= Must be Imaged!
2D Barcodes

• Invented in the early 90’s

• Data capacity to carry 100’s of bytes of data
  • More than just a database address

• Error correction for robustness and tolerance to symbol damage

• Imaging scanner performance was limited until 2002-03 time frame
  • Reader performance was enabled by advancements in image sensors and embedded processors
2D Barcodes

- ID cards and driver’s licenses
- Postage E-stamps
- Shipping labels
- Cosmetics
- Consumer goods
- Direct part marks (DPM)
Dot peen (aka: rapid indent, pin stamp)
DPM

Laser etch
• **Image sensor array**
  • A 2D array of light sensitive elements that convert photons to electrons
  • A read-out circuit that accesses the elements and converts the electron charge signal to a digital number

• **When an image is formed on the array with a lens the elements produce a picture**
  • The elements are referred to as pixels (picture elements)
• **CCD (Charge Coupled Device)**
  • Charge is read-out by shifting it sequentially through a chain of parallel capacitors
  • The charge is converted to a voltage by a single amplifier
  • The voltage is converted to a digital number on a separate IC
Basic CCD Pixel Structure

CCD Photodetector

Photogate

Photodiode

CCD Shift Register
Frame Transfer Architecture

Interline Transfer Architecture

- Imaging Area
- Optical Black Pixels
- Storage Area (shielded)
- Horizontal Shift Register

- Imaging Area
- Vertical Shift Register
- Photodetectors
- Output Amplifier
- Analog Video Signal
CCD Image Sensor Array
Read-out

Progressive Scan
Frame read in a single field

Interlaced Scan
Frame read in two fields (odd and even)
Typical CCD Camera System Electronics
Commercial CCD Cameras

Studio camera (>$10,000)

Hobbyist camera (<$500)

Professional camera (>2,000)
• **CMOS (Complementary Metal-Oxide Semiconductor)**
  
  • Charge is converted to a voltage in the pixel with a source follower amplifier
  
  • The voltage signals are read-out by a sequential addressing scheme
  
  • The voltage is converted to a digital number on the same IC
Basic CMOS Pixel Structure
CMOS Image Sensor Array Architectures

Single ADC Architecture

- row address register
- clock generator and address control
- active pixel sensor array
- analog multiplexer
- column decoder
- column address register
- high speed A/D converter

Column Parallel ADC Architecture

- row select shift register
- active pixel sensor array
- column parallel ADCs
- digital multiplexer
- column select shift register
CMOS Image Sensor Array Read-out (rolling shutter)

Instantaneous image of object on CCD surface

Image collected by a progressive scan CCD

Image collected by a rolling shutter CMOS sensor
CMOS Pixel for Progressive Scan (snap shutter) Read-out
Typical CMOS Camera System Electronics (monolithic IC)
Commercial CMOS Cameras

- Low end consumer camera (<$200)
- USB video camera (<$50)
- Toys (<$30)
- Mobile Phone Cameras (<$20)
CCD vs. CMOS Camera Architectures
# CCD vs. CMOS Advantages

<table>
<thead>
<tr>
<th>CCD Advantages</th>
<th>CMOS Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Greater sensitivity</td>
<td>• Small camera size</td>
</tr>
<tr>
<td>• Lower noise</td>
<td>• Lower power dissipation</td>
</tr>
<tr>
<td></td>
<td>• Integration of ASSP</td>
</tr>
<tr>
<td></td>
<td>• Single supply voltage</td>
</tr>
<tr>
<td></td>
<td>• Lower cost</td>
</tr>
</tbody>
</table>
CCD vs. CMOS Sensitivity and Noise

CCD
• Optimize sensitivity with custom fabrication process
• High fill factor
• Pixel to pixel variations are minimal
• kT/C noise can be minimized

CMOS
• Fabless companies use standard fabrication process
• Low fill factor
• Pixel to pixel circuit variations are significant
• kT/C noise in the pixel
\[
\tan \left( \frac{\phi}{2} \right) = \frac{x}{2s'}
\]

\[
\frac{1}{f} = \frac{1}{s'} + \frac{1}{s}
\]
Imaging Basics

Lens F# = f/D

Depth of field is proportional to 1/D and resolution is proportional to f

Lens throughput

\[ \frac{1}{4F^2} \]
Focus

\[ F\# = \frac{f}{D} \]

Depth of focus is determined by the focal length and aperture diameter.
Diffraction

The effect of Light bending around obstacles (aperture)

Limit of resolution

\[ \Delta \ell_{\text{min}} = \frac{1.22 \, f \lambda}{D} \]
Modulation Transfer Function

**Optics (circular aperture)**

\[
MTF_{\text{optics}}(f, w) = \frac{4}{\pi} \int_{0}^{1-f} \cos(8\pi wrf) \sqrt{1 - (f + r)^2} \, dr
\]

**CCD**

\[
MTF_{\text{ccd}}(f, \theta) = \left| \max \left( \frac{p_y \sin(\theta)}{p_x \cos(\theta)} \right) \right|^{-1} \cdot \frac{\left( u_2(\theta) \sin(\pi f u_2(\theta)) \right)^2 - \left( u_1(\theta) \sin(\pi f u_1(\theta)) \right)^2}{u_2(\theta) - u_1(\theta)}
\]

if \( u_2(\theta) = u_1(\theta) \)

otherwise

**Optics (rectangular aperture)**

\[
MTF_{\text{optics}}(f_x, f_y, w_x, w_y, \theta) = \Lambda(f_x \cos(\theta)) \cdot \text{sinc}(8\pi w_x f_x \cos(\theta)(1 - |f_x \cos(\theta)|)) \cdot \Lambda(f_y \sin(\theta)) \cdot \text{sinc}(8\pi w_y f_y \sin(\theta)(1 - |f_y \sin(\theta)|))
\]
Light Throughput of the Lens

The amount of light collected from an object of size $A_{\text{object}}$ at a distance $s$ from the lens is

$$\frac{A_{\text{object}} A_{\text{aperture}}}{\pi s^2}$$

If the aperture is circular, then this can be reduced to

$$\frac{1}{4F^2 (1+m)^2}$$
Depth of Field vs. Resolution

- Nominal focus for VGA (~24”)
- VGA depth of field (~12” to ∞)
- SVGA depth of field (~15” to ~45”)
- Lens position

VGA depth of field (~12” to ∞)
Depth of Field vs. Resolution

Nominal focus for VGA (~24”)

Nominal focus for SVGA (~48”)

SVGA depth of field (~25” to ∞)

VGA depth of field (~12” to ∞)

lens position
• RISC microprocessor core with rich set of peripherals (e.g., USB)

• High speed (48 MHz) image acquisition channel

• SDRAM, FLASH
Decoder Software

- Image acquisition
- Camera control
- Automatic gain/exposure control
- Aiming/illumination control
- Video/picture/barcode mode
- Image processors for barcode decoding
- Host communication
• Locate the barcode in the image
• Digitize the bar (1D) or module (2D) pattern
• The pattern is passed to a decoder to determine the data content
• Auto-discriminate the type of barcode
Aiming Pattern

• Projected on the target to assist the user in aiming at the barcode

• Laser or LED technology with diffractive or conventional optics

• Displays are not useful because the attention of the user is on the barcode
• Projected on the target to provide reflected light to the camera

• Enables scanning in dark environment

• Decreases exposure time to limit the effect of hand motion
Host Communications

• Corded
  • USB, RS232, Keyboard wedge

• Cordless
  • Bluetooth, custom

• Wireless
  • WiFi, WAN
SE4400 Imaging Engine

- Laser-like scanning aggressiveness
- Basic building block for our imaging-based mobile computers and industrial scanners
  - Smart focus optics (5” and 9”)
  - CCD sensor array
  - Laser aiming
  - Built-in LED illumination

LED Illuminator
Smart Focus
Laser Aimer
Camera Aperture
Smart Focus

- Enables larger aperture because depth of field is maintained with two focus positions.
- Enables a wide range of barcode densities to be read with one product.
Imaging Products

Mobile computers

- PDT8100
- MC9000K/S/G
- MC3000
- MC50
Key Technologies

PL4407 Decoder MCM

- Freescale MXL with Arm9 core
- 150 MIPS
- 100 mA @ 3V
- 8 MB SDRAM
- 2 MB Flash
- Video port
Digital (Imaging) Scanners

• Industrial scanners
  • DS3407/08 corded
  • DS3478 cordless
• DS6707/08 retail digital scanner
  • 1.3 MP resolution
  • Fixed focus optics
• OEM
Thank You For Your Time And Attention!
Questions