INCREASE MACHINE VISION THROUGHPUT AND REDUCE COSTS

Upgrading from CCD to CMOS Sensors

07/02/2020
Today’s Agenda

• How to increase performance and lower costs by transitioning from CCD to CMOS imaging sensors

• Pro’s and Con’s of modern interface standards, such as USB 3.1, GigE, 10GigE and more

• Understanding key parameters like QE, Absolute Sensitivity Threshold, Read Noise and how they help you chose the right camera for your specific application

• Emerging next-generation machine-vision CMOS sensor technology

• Q&A session to ask our imaging experts questions on your specific machine-vision camera selection and deployment
Speaker Bio

Mike Fussell, MBioEnt, B.Sc.

Product Manager, Machine Vision

• 4 Years with Point Grey Research and FLIR

• 7 years of experience in spherical and machine vision
FLIR Systems, Inc. designs, develops, manufactures, markets, and distributes technologies that enhance perception and awareness. We bring innovative sensing solutions into daily life through our thermal imaging systems, visible-light imaging systems, locator systems, measurement and diagnostic systems, and advanced threat detection systems. Our products improve the way people interact with the world around them, enhance public safety and well-being, increase energy efficiency, and enable healthy and entertained communities.

Visit us at: flir.com/machine-vision
Over 20 Years in Machine Vision

We delight the world with groundbreaking intelligent sensing solutions that advance productivity, safety, and health.

Starting out as Point Grey Research in 1997, FLIR machine vision is today a key provider of advanced digital cameras and stereo people counting devices around the world.
• Helping you be first to market with the latest imaging technology

• Providing you access to a broad portfolio with choices in interface, resolution, and performance

• Giving your team an SDK designed for faster and easier system development

• Providing dependable products: 3 year warranty; Certified ISO 9001

• Help wherever you are: Global presence for sales, service, and support
Quality Management

- ISO 9001:2015 quality management system
- Dedicated SMT lines for high capacity manufacturing
- High quality control with 3D AOI, X-ray inspection, and industrial clean room
- Automated test stations (optical + thermal)
- "Seal of Quality" label guarantees 100% test and inspection
- High quality test specifications & documentation
Applications We Serve

• **Industrial**: electronics inspection, 3D scanning, food inspection
• **Medical and life science**: microscopy, blood testing, pharma, surgery
• **Intelligent Traffic Systems (ITS)**: red light, speed, access control
• **Autonomous guidance**: vehicles, robots, forklifts, UAS
• **Biometrics**: fingerprint, iris, and facial recognition
• **Entertainment**: VR, broadcast, motion tracking
• **Retail**: counting, tracking, queue management, shopper conversion
• **Geographic Information Systems (GIS)**: street mapping, surveying
FireWire and CCD are going away. Now what?

- Apple launched their last FireWire product in 2008

- The computer industry no longer manufacturers supporting FireWire peripherals

- Sony announced CCD discontinuation in 2015

- How can I select a replacement camera with modern CMOS sensors?

Remember when this was the best phone you could get?

It’s still more recent than the discontinuation of FireWire as a consumer interface.
Parameters when Selecting a Replacement?

Key Specifications and Parameters to Consider When Selecting a Successor Camera:

- **Sensor**
  - Sensor resolution
  - Sensor size (format)
  - Pixel size
  - Imaging performance
- **Interface**
- **Form-factor**
- **Lens Mount**
- **GPIO**
- **SDK Support**
Wide Variety to Choose From

- **Good news**: Replacement options are plentiful
- **Bad news**: The answer to “what is the best replacement option” is always 
  - *it depends.*
## CCD vs. CMOS: Price-to-Performance

<table>
<thead>
<tr>
<th></th>
<th>Price</th>
<th>Camera Model</th>
<th>Resolution</th>
<th>Sensor</th>
<th>Format</th>
<th>Interface</th>
<th>Pixel Size</th>
<th>Frame Rate</th>
<th>Quantum Efficiency</th>
<th>Full Well Depth</th>
<th>Temporal Dark Noise</th>
<th>Dimensions</th>
<th>Mass</th>
<th>Dynamic Range</th>
<th>Read Method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Price</strong></td>
<td>$2,000.00</td>
<td>GS2-FW-14S5M-C</td>
<td>1.4 MP (1384 x 1036)</td>
<td>Sony ICX285 Monochrome CCD</td>
<td>2/3&quot;</td>
<td>FireWire B</td>
<td>6.45um</td>
<td>30 FPS (Full Resolution)</td>
<td>59% @ 525nm</td>
<td>19,845e</td>
<td>10.79 e</td>
<td>44mm x 29mm x 58mm</td>
<td>104 g</td>
<td>68.28 dB</td>
<td>Global Shutter</td>
</tr>
<tr>
<td><strong>Price</strong></td>
<td>$885.00</td>
<td>BFS-U3-28S5M-C</td>
<td>2.8 MP (1936 x 1464)</td>
<td>Sony IMX421 Monochrome CMOS</td>
<td>2/3&quot;</td>
<td>USB 3.1</td>
<td>4.5um</td>
<td>130 FPS (Full Resolution)</td>
<td>76% @ 530nm</td>
<td>10,940 or 25,219 (Mode Dependent)</td>
<td>2.65 e</td>
<td>29mm x 29mm x 39mm</td>
<td>53 g</td>
<td>71 dB</td>
<td>Global Shutter</td>
</tr>
</tbody>
</table>
Objectives of the Migration?

• What are the specifications of the outgoing camera?
• Is a direct replacement needed?
• Are you looking for a performance increase?
• Are you looking to reduce costs or system size?
• Are you using existing optics or considering improvements?
• Is the image being viewed by a human on a display or a computer in software?
Sensor Selection

- The sensor is the heart of the camera
- Sensor characteristics define the image which a camera will capture
- Key characteristics are:
  - Resolution
  - Optical format & aspect ratio
  - Pixel size
  - Imaging performance
Resolution vs. Speed (FPS)

- For any given interface, speed (FPS) and resolution are interdependent.
- \( \text{FPS} = \frac{\text{Interface speed}}{[(\text{horizontal resolution}) \times (\text{vertical resolution}) \times (\text{bit-depth})]} \)
- Lower resolution is faster than higher resolution.
- Note: BayerRGB (RAW) is faster than RGB:
  - BayerRGB = 8-bits per pixel, interpolation performed at host.
  - RGB = 24 bits per pixel, interpolation done on camera.
Optical Format

- The optical format is the diameter of the circle the sensor would fit into.
- Typically measured in inches.
- Aspect ratio is the difference between horizontal and vertical dimensions.
- Larger optical formats require larger lenses to cover the full area of the sensor (typically more costly).
- For optimum performance, lens format should equal sensor format.
Pixel Size

Pixel size, resolution and optical format are interdependent

• Smaller pixels enable a higher resolution sensor of the same optical format
• Or a smaller optical format for the same resolution

Original Design

Decreasing pixel size results in higher pixel density / resolution for the same size sensor

Same resolution using more cost-efficient smaller optical format
Imaging Performance

- How sensitive the sensor is
- The brightest and darkest details a sensor can resolve
- The order that lines of the image are captured in
Quantum Efficiency

• % of incoming photons converted to electrons

• The max QE at 525nm is often used as a measure of sensitivity

*Does not tell the whole story*
QE varies by wavelength

- QE is not the same across the spectrum
- Silicon only works for a narrow band of wavelengths
- RGB filters reduce this even more
- Knowing what wavelengths are critical can help match a sensor to an application
Near Infrared (NIR)

- Long wavelengths typically have a low QE on CMOS and CCD sensors
  - Some sensors are optimized to have higher QE in these wavelengths, however standard Sony Pregius sensors are better
AST combines QE and Read Noise

- Absolute sensitivity threshold is what really matters
- The weakest signal at a wavelength that a sensor can reliably detect
- Combines QE and read noise
Saturation Capacity

• Saturation capacity is a measure of how much light a pixel can capture before it is full
  • Saturation capacity is the amount of charge a pixel can hold
  • Determined by the size of the photodiode
  • Bigger pixels generally have a better saturation capacity
Dynamic range

- Ratio between the brightest and darkest value in an image
- Limited by bit-depth of display
  - The camera can capture much more information than can be displayed on a monitor, so software will always see much more information than a human viewing the image on a screen.
Readout

- Most industrial applications prefer global shutter
- Moving objects will be distorted on rolling shutter sensors
- Sometimes a tradeoff can be made for the lower cost of rolling shutter sensors
  - More light for shorter exposures or slow the object
  - Global reset can help, but that introduces other issues

Rolling Shutter  Global Shutter
Summing up: CMOS is better*

- CMOS is almost always better except for temporal dark current
What’s New in 3rd Gen Pregius?

• Selectable Conversion Gain enables the user to switch between high gain / low saturation capacity and low gain / high saturation capacity modes.

• In high conversion gain mode, the sensor behaves similar to a second generation Pregius sensor.

• Does not change AST.
What’s new in 4th Gen? (Pregius S)

• New pixel design enables large sensors to work well with compact and inexpensive C-Mount lenses saving space – and money!

• There are trade-offs, so larger lens mounts will also be available when maximizing spatial resolution and sharpness across the whole frame is critical

• Fixed conversion gain

1.1” IMX253
C-Mount lens @ f/2.8

4/3” IMX530
C-Mount lens @ f/2.8
4th Generation Pregius S

- Exciting new sensor technology (literally) turning normal rules of sensor design upside-down!
- Initial models are planned for Q2 - as soon as production sensors are available from Sony
- The rollout will prioritize sensors which enable new applications and customers over sensors which deliver improvements for existing ones
How does 3rd and 4th Gen Pregius Compare?

- New pixel structure delivers big improvements in Quantum Efficiency and Absolute Sensitivity Threshold
- 4th Generation is not a replacement for 3rd Generation
Machine Vision Interfaces
USB 3.1 Gen 1

- Fast 5 GBPS of image data bandwidth
- Limited to 5-meter maximum cable length
- Power and data on a single cable
- Direct Memory Access (DMA) uses minimal CPU and memory
Gigabit Ethernet

- 1 GBPS of image data bandwidth
  - 98% efficient encoding protocol
- 100-meter maximum cable length
- Higher resistance to Electromagnetic Interference (EMI)
- IEEE1588 PTP for sub-microsecond resolution timestamp synchronization
- Must either be powered externally or via PoE
- No DMA, so not ideal for embedded systems
New 10-Gigabit Ethernet

• Same rules apply as 1-GigE, however provides faster throughput (10Gpbs vs. 1Gbps)
• 10GigE standard is rapidly gaining acceptance
• Perfect for ultra-resolution applications (i.e. virtual reality, 360 degree rendering, etc)

FLIR Oryx 10GigE camera offers 31MP resolution at 26fps via APS-C format Sony IMX342 sensor
Changing form factor presents two challenges:

- Case dimensions may be different (fortunately, it is easy to go smaller than larger)
- GPIO changes

Older CCD based camera with larger 44 mm × 29 mm × 58 mm design

Modern design incorporates 29mm x 29mm x 30mm footprint

Board-level form-factor for embedded systems (29mm x 29mm x 12mm)

27mm x 27mm x 14.5mm compact design for embedded systems and entry-level applications
Lens Mount

- C-Mount cameras support the larger lenses required by larger sensors
- CS-Mount cameras support the smaller lenses used by smaller sensors (max 1/1.8”)
- The CS-Mount is 5 mm shorter than the C-Mount
- CS-Mount can be converted to C-Mount via 5mm extender ring
- CS-Mount lenses cannot be converted to C-Mount
- Larger format sensors utilize F-Mount or TFL
- S-Mount for small sensor / embedded applications

Modular design allows for both F-Mount or Emerging TFL-Mount
• Newer cameras have a different GPIO layout

• Few customers use all GPIO pins
  • More flexible GPIO on BFS eliminates need for as many dedicated pins
  • Logic Blocks can build more complex GPIO functions, potentially combining lines
CMOS will be with us for a long time

- Unlike CCDs, CMOS image sensors can be produced using the same equipment as other semiconductors.
- Since they don’t require dedicated production facilities, the economics of CMOS manufacturing are much more favorable.
- Unlike CCDs, CMOS sensors do not require specialized components to support their operation in cameras.
- Sony has not provided a lifetime guarantee for their CMOS sensors, though they have said they will continue to make them if people continue to buy them.
- Even first generation Pregius sensors (IMX174, IMX249) still sell very well.