Color CMOS Cameras

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International Robots & Vision Show
Rosemont, IL
June 3, 2003

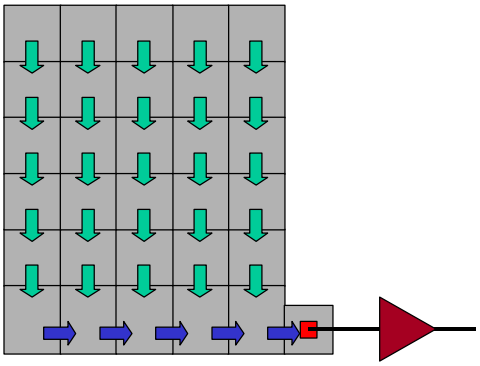
CCD sensors seemed to be doing just fine …

- … so why start making sensors in CMOS?
- CMOS sensors
  - Can accommodate other functions on-chip
  - Use cheaper, more common production processes
  - Allow access to pixels individually
  - Dissipate very little power and use lower voltages
  - Work from real digital drive signals
- But, CMOS sensors
  - Have a higher noise floor
  - Require circuitry in every pixel, affecting fill factor
- The bottom line:

Flexibility & Cost

Readout Architectures - CCD

- CCDs charge is moved vertically then horizontally and detected at one node.



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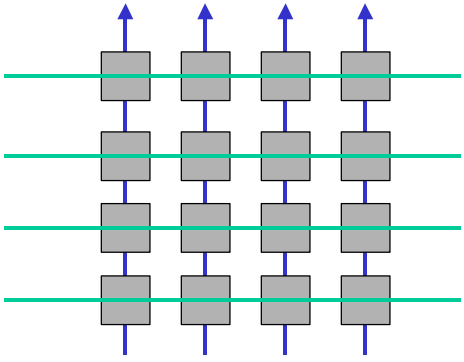
Readout Architecture - CMOS

- In CMOS imagers a row is selected and the pixels each put a voltage on a column bus



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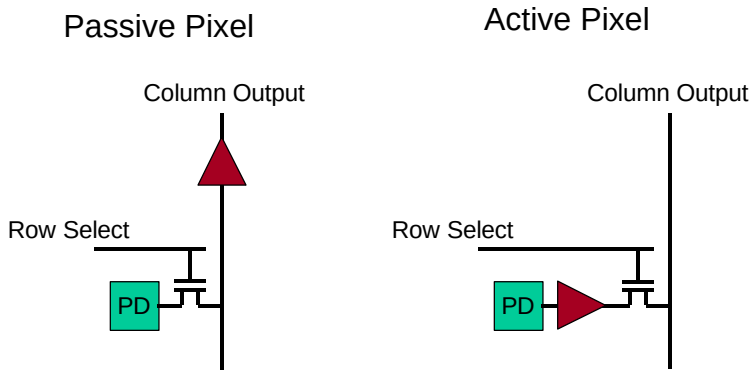
CMOS Bus Varieties



✓ Higher Fill Factor

✓ Lower Fixed Noise

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More CMOS Varieties

- Active Column Sensor ™
  - Pixel amplifier is split between the pixel and the column
  - Improve fill factor
  - Photon Vision Systems
- Digital Pixel System™
  - Pixel is sampled at high speed to determine time to preset threshold
  - Increase dynamic range
  - Pixim
- Well Pixel
  - Charge is accumulated in the entire substrate
  - Improve fill factor
  - FillFactory
- Active Reset
  - Photodiode is reset with feedback amplifier
  - Reduce noise
  - Pixel Devices (Agilent)

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On-Chip Functions

- Computer Bus Interface
- Scan Control
- Shuttering
- Gain Control
- A/D Conversion
- Image Processing

- Camera-on-a-Chip (and more)

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Scan Control

- Region of Interest
  - Setting horizontal and vertical scan boundaries
- Binning
  - Combining pixels horizontally or vertically
- Skipping
  - Scanning only selected rows or columns
- Triggering
  - Starting scan on an external command
- Scan Direction
  - Scanning up or down in the selected area

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Exposure Control

- Synchronized Illumination
  - Entire sensor is reset on external command
  - Readout starts after a specified delay
  - Requires reading out in the dark
- Rolling Shutter
  - Lines are reset in sequence
  - Line readout occurs after a fixed delay
  - May produce motion artifacts
- Global Shutter
  - Entire sensor is reset
  - Signals are sequestered after a fixed delay
  - Requires additional pixel complexity

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A/D Conversion

- Off-Chip
  - Sensor output is analog
  - Converters are separate
  - Can have multiple outputs
  - No A/D heating of chip
  - Very fast, few pins
- Serial
  - One A/D for the whole chip
  - Requires high A/D speed
  - Moderate power use
  - Single output port
  - A/D can limit speed
- Multiplexed
  - A/D for column group
  - Low conversion rate
  - Can be micropower
  - Single shared output port
  - Bus can limit speed
- Parallel
  - A/D for column group
  - Low conversion rate
  - Can be micropower
  - Port for each A/D
  - Very fast, many pins

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Color Separation Technologies

- Sequential Exposure
  - Monochrome sensor
  - Expose several times with different bandpass filters
- Multi-chip Assembly
  - Multiple monochrome sensors
  - Filters on prisms separate bands
- Color Filter Array
  - Monochrome sensor
  - Each pixel has a specific bandpass filter on it
- Layered Photodiodes
  - Color sensor- three photodiodes per pixel location
  - No filters, stacked structure provides color separation
- All require infrared cut filters

Sequential Exposure Techniques

- Use monochrome sensor
- Make a series of exposures with different spectral bands
- Common methods in use
  - Filter wheel – arbitrary filter curves possible
  - LCD filter – narrowband or wideband
  - Filtered illumination – for closed systems

Multi-Chip Assemblies

- Split incoming light into multiple spectral channels and direct each to a monochrome sensor
- Generally use a prism with trim filters
  - 3-5 channels available
  - Preserves full sensor resolution
  - Requires large clear distance behind lens
  - Can restrict usable f/number

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Color Filter Arrays

- Uses monochrome sensor with a filter placed on each pixel
- Only one sensor required for simultaneous acquisition
  - Several arrangements are used
    - Bayer quad, diagonal, stripe, common neighbor layouts
    - RGB, CMY, CMGW and other filter sets
  - Color data is offset geometrically
  - Some light is lost in filter absorption
  - Organic filter materials age

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Layered Photodiodes

- One sensor with stacked photodiodes at each pixel location
- Band separation uses absorption curve of silicon
  - Band spectral shape is determined by physics and CMOS process
  - Geometrically accurate and stable
  - Monochrome and color resolution are equal
  - Requires accurate color transformation matrix

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Camera Types Available

- Small – some will fit in cellphones
- Standard Interfaces
  - Analog – RS-170, etc
  - Digital – LVDS, CameraLink, FireWire, USB
- Fast – Multiple outputs to 1000+ fps
- Versatile – multiple scan modes
- Integrated – smart cameras
- More to come

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