Fundamentals of Embedded Computer Vision: Creating Machines That See

Day 2: Fundamentals of Image Sensors for Embedded Vision

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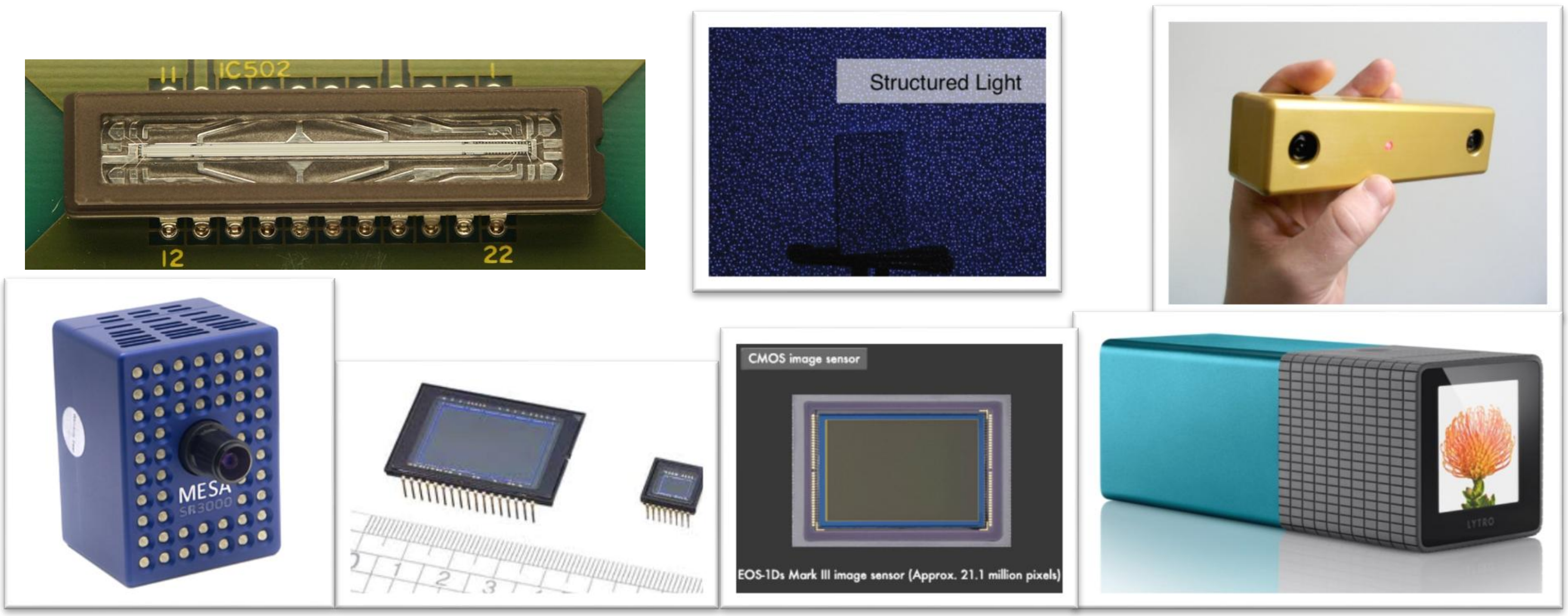
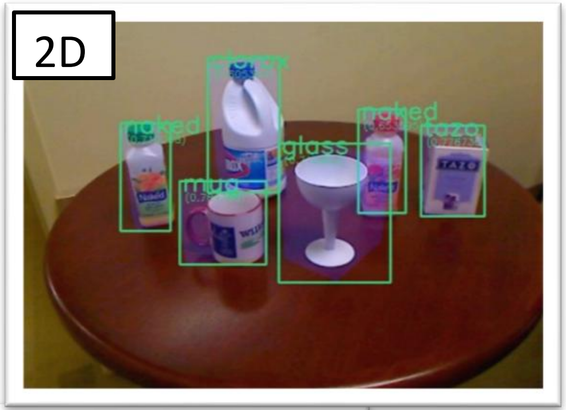
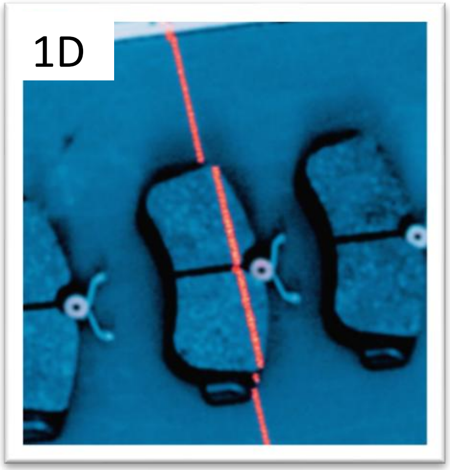
Sensors—The "Eyes" of Any Embedded Vision System

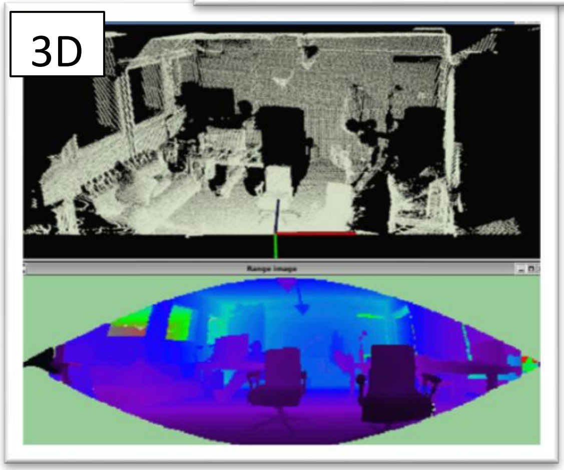
Many types of sensors are available for embedded vision systems

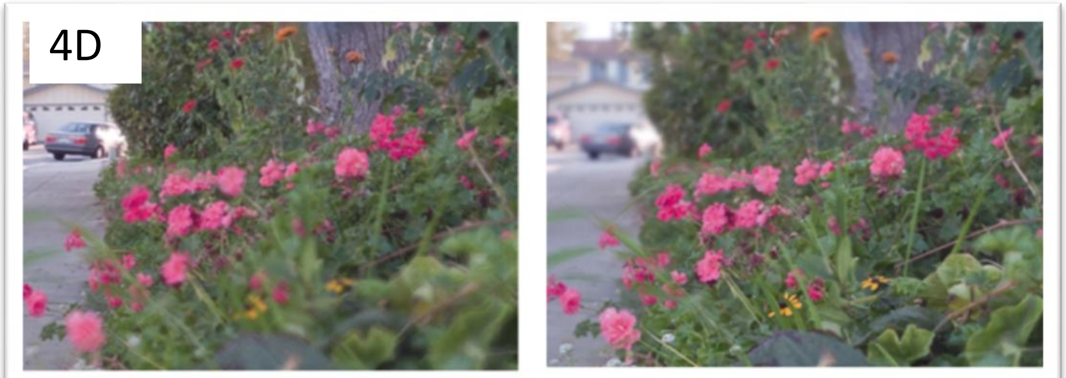


Embedded Vision Sensor Types





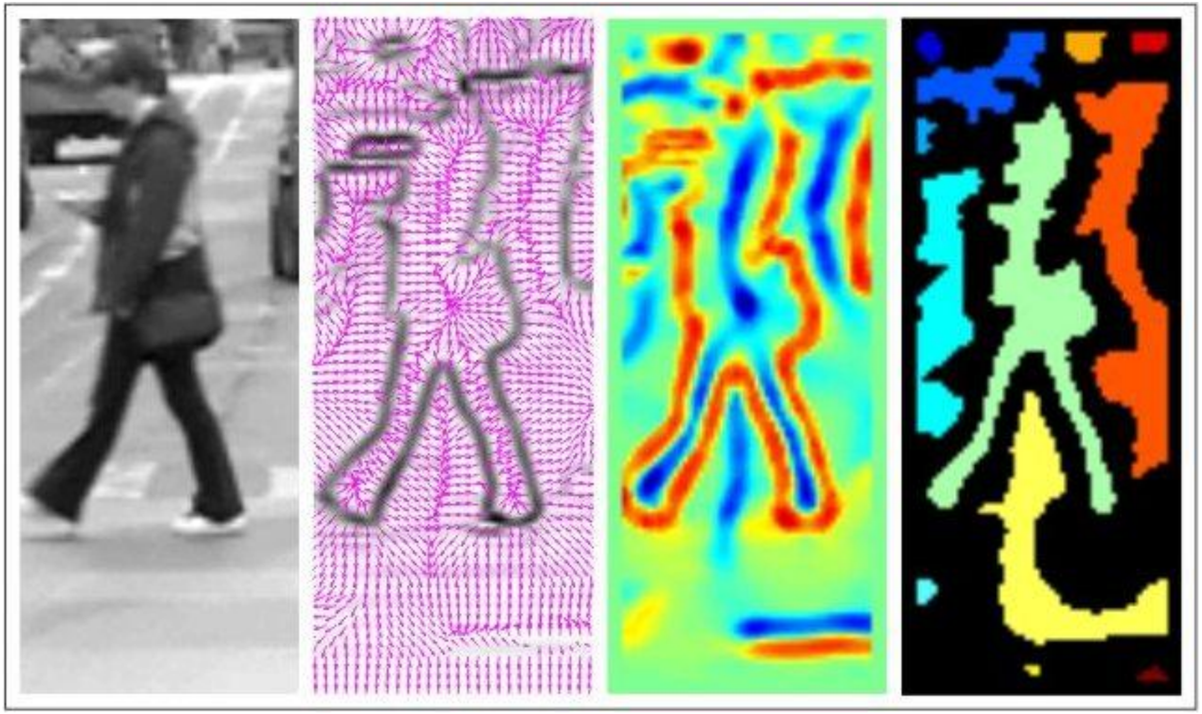




Source: "The Multi-Focus Plenoptic Camera" by Todor Georgiev & Andrew Lumsdaine

2D SENSORS

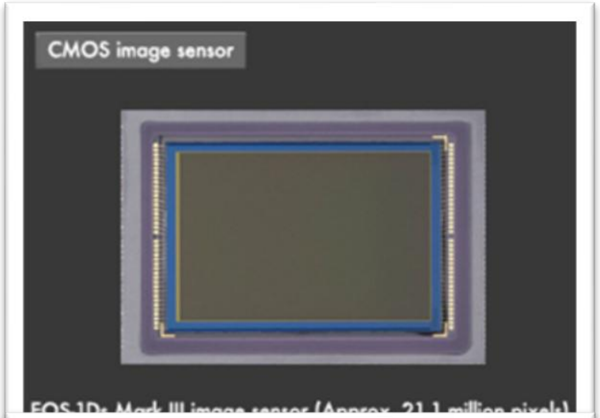
2D Sensors

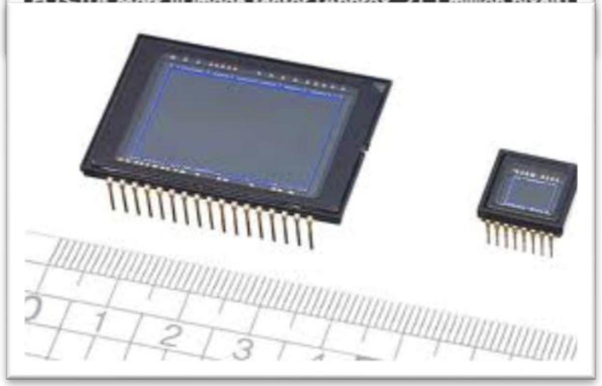


http://withfriendship.com/user/sathvi/computer-vision.php

The Most Popular 2D Sensors are CCD and CMOS

- 2D sensors capture a 3D scene on a 2D plane
- 2D sensors are a relatively low-cost method of sensing the environment
- It takes more processing to use the information from a 2D sensor
- A 2D sensor trades hardware cost for software cost
- CCD (Charge Coupled Device) and APS (Active Pixel Sensor—commonly referred to as CMOS) are the two most common technologies used for 2D sensors
- CCD is more sensitive to IR and UV but tends to cost more



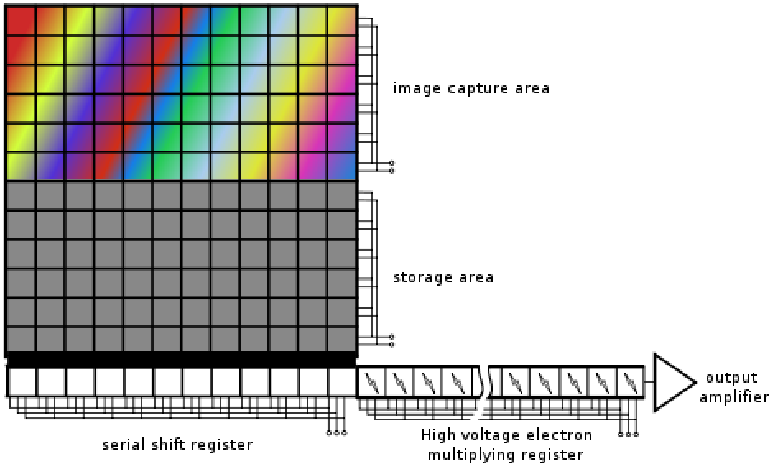


2D Charge Coupled Device (CCD)

- Most common sensor used in computer vision applications
- Invented in 1969, technology is very well understood
- Single amplifier provides a more uniform pixel response than CMOS sensors
- Individual pixel elements are more sensitive than CMOS pixel elements
- More sensitive to IR and UV than CMOS sensors
- Detecting color requires a filter (Bayer)
- Best choice for low-light applications or applications in non-visible wavelengths

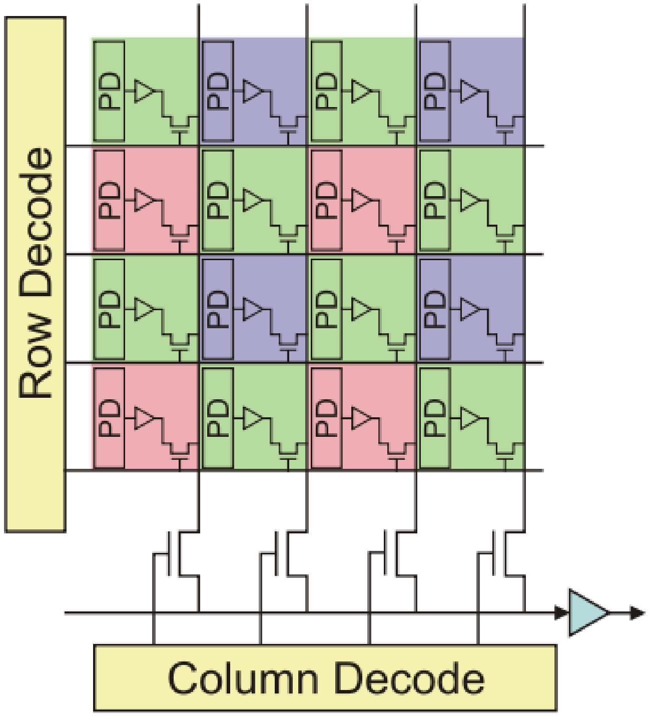
CCDs have traditionally established the performance benchmarks in photographic, scientific, and industrial applications that demand the highest image quality.

Manufacturers: Sony, Kodak, SITe, DALSA



2D Active Pixel Sensors (CMOS)

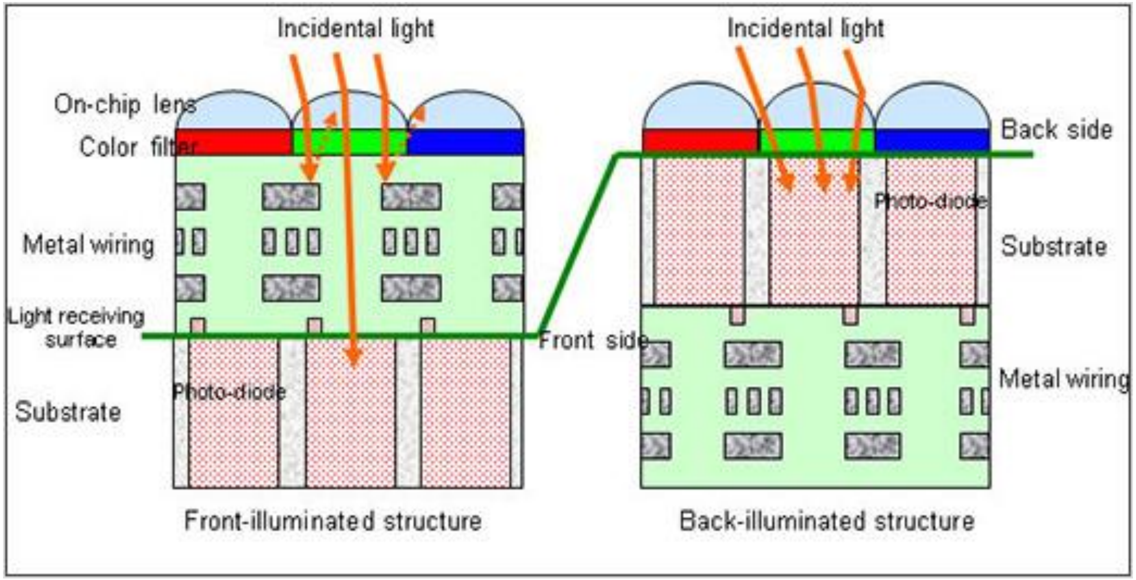
- "CMOS sensor" is the common term used to describe an Active Pixel Sensor (APS)
- CMOS sensors are low-power devices commonly used in battery powered systems like smart phones
- Each pixel has its own signal amplifier resulting in slight differences in gain between pixels
- Slight differences in gains require compensation
- Active part of each pixel leaves less space for light-sensitive portion resulting in lower overall light sensitivity



Manufacturers: Canon, Sony, Avago, Micron, Omnivision, PixelPlus, PhotonFocus

Sony "Exmor R" Back-illuminated CMOS Sensor Technology

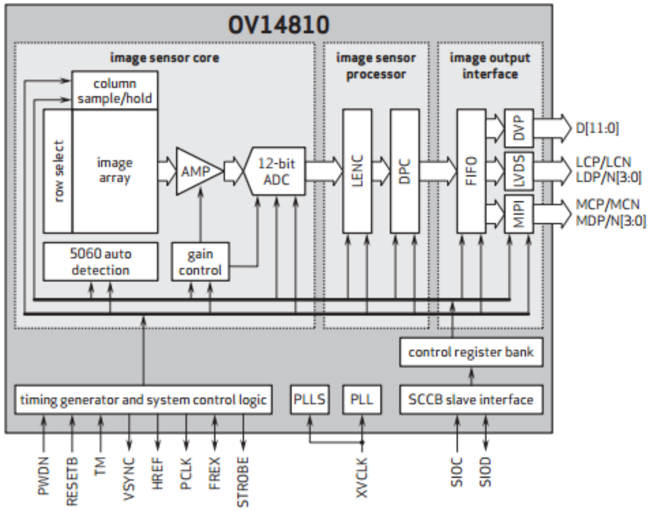
- A game-changing technology: light sensitivity of CCD with low power of CMOS
- Larger area of photo diode exposed to light
- "A signal-to-noise ratio of +8 dB (+6 dB sensitivity, -2 dB noise) in comparison to existing Sony CMOS image sensors of the same pixel size"
- 5MP camera used in iPhone 4S (rumored to cost around $10)



2D Chip Camera (CMOS Sensor with Integrated Processing)

- Chip cameras are a class of CMOS sensors used heavily in mobile devices (cell phones and tablets)
- Chip cameras are CMOS sensors coupled with built-in Image Sensor Processors (ISP) for basic camera functionality
- The ISP handles lens correction, auto exposure, white balance, …
- Chip cameras are designed to connect directly to application processors
- Pricing is very quantity-dependent and secretive
- Omnivision, Sony, Aptina

Functional Block Diagram

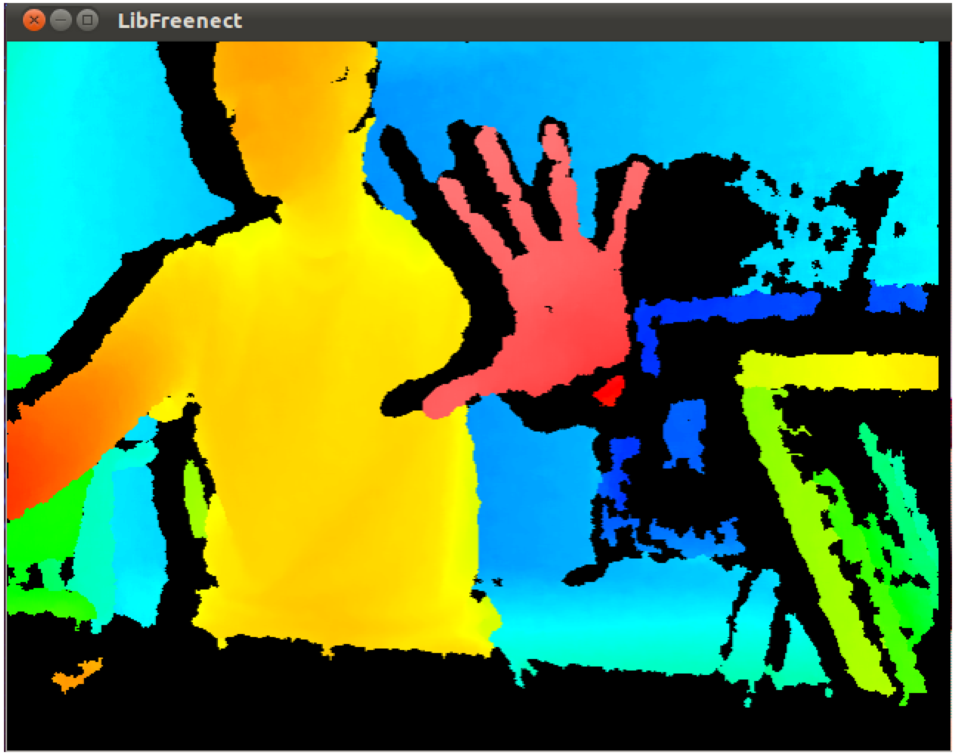


3D SENSORS

3D Sensors

Primary Output of 3D Sensors is a Depth Map

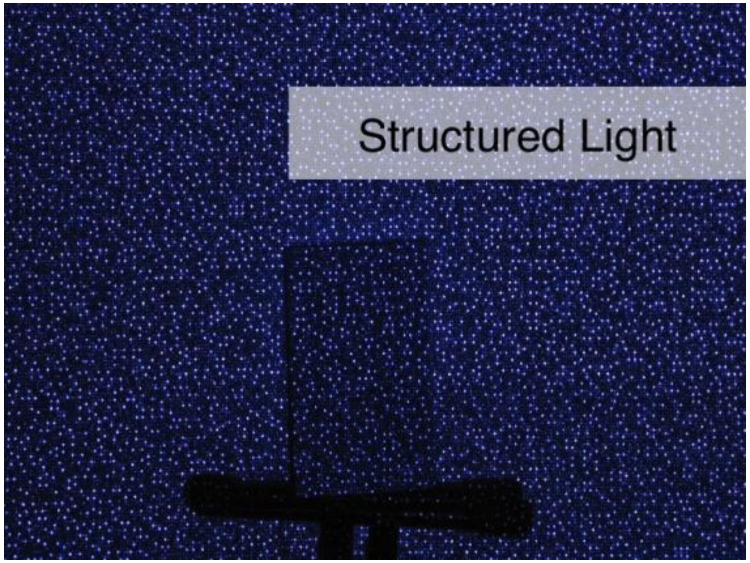
A depth map is an image matrix in which each entry represents the distance between the sensor and a point in front of the sensor

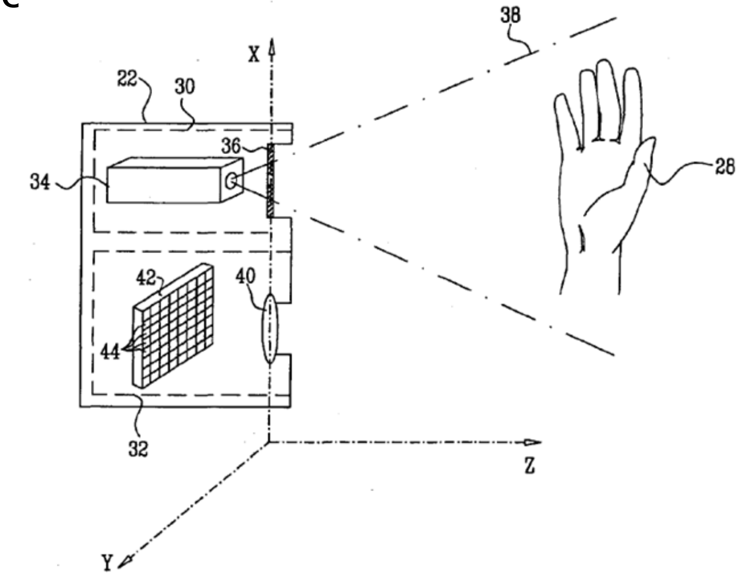


3D Via Structured Light

Structured light is the method of projecting a predetermined pattern of light on to a scene, for the purpose of analysis

Sensors based on the structured light method use a projector to project the light pattern, and a camera to sense the result





Freedman et al, PrimeSense patent application US 2010/0290698

3D Via Structured Light (Kinect)

The Microsoft Kinect uses an astigmatic lens with different focal lengths in the X and Y direction. An infrared laser behind the lens projects an image consisting of many dots that change shape and orientation depending on how far the object is from the lens. A projected circle changes to an ellipse whose orientation depends on depth.

astigmatic lens

IR laser

IR sensitive
2D camera

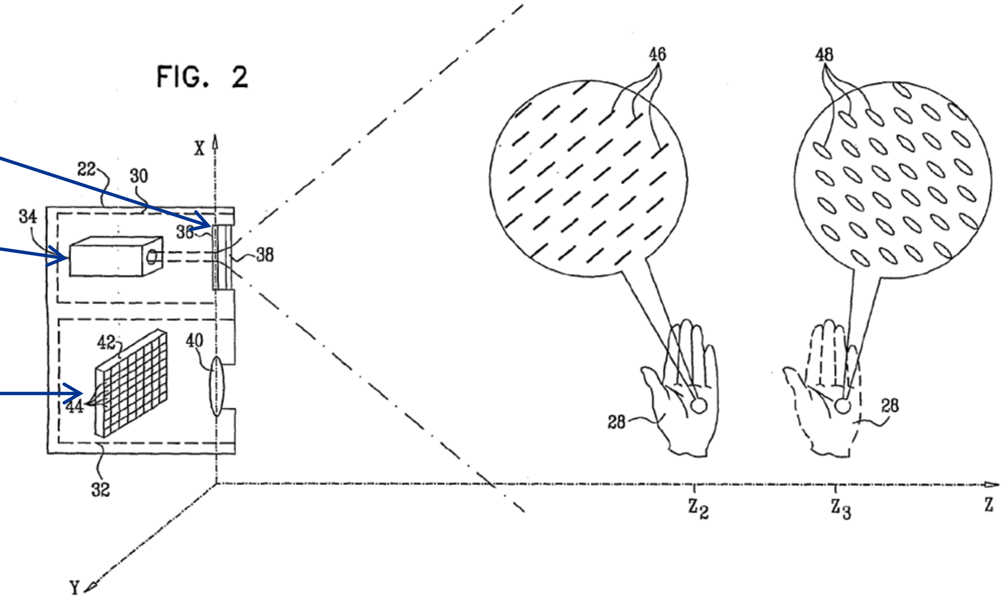


FIG. 2

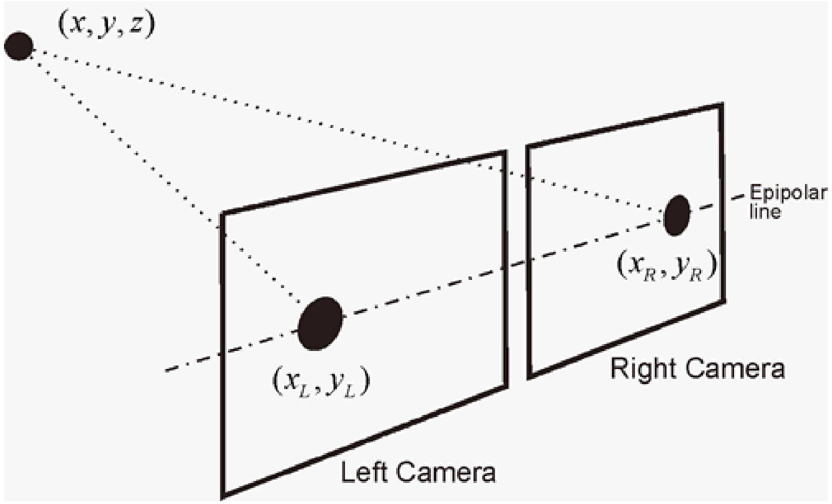
3D Via Structured Light (Kinect)

- Advantages
  - Simpler algorithms
  - Low cost processing
  - Resolution
  - Accuracy

- Disadvantages
  - Issues projecting outdoors or in sunlight
  - Power (projector can require a lot of power)
  - Custom projector lens

3D Via Stereo Imaging

- Stereo triangulation infers depth from two images (can extend to multi-view geometry)



- 3D stereoscopic vision is employed in myriad applications (robotics, military, industrial machine vision, surveillance)
- Stereo sensors can be either discrete or integrated

3D Discrete Binocular Stereoscopic Sensors

- Discrete binocular sensor achieved by basically bolting two cameras together

Point Grey Bumblebee®

FujiFilm FinePix Real 3D W1

Minoru 3D Webcam

- Both cameras need to be calibrated for robust image registration
- Frames need to be synchronized if stereo camera or subject is moving

3D Integrated Dual Stereoscopic Sensors

- Integrated dual sensors combine two image sensors in a single SoC and output a combined stream over a single bus
- Advantages:
  - Packaging, versus discrete sensors which link two cameras together with comparatively little combined control. (Analogy: two motorcycles linked together with an axle do not make a car!)
  - Better frame synchronization (accommodates faster motion)
  - Tighter integration leads to better calibration, which in turn yields better stereo (increased depth perception and faster image processing turnaround because less of the image needs to be searched)
- Examples:
  - Lattice Semiconductor (MachXO2) and Aptina (MT9M024/MT9M034 720p) Stereo Camera Reference Design (CES 2012)
  - Meduza MK1

CONCLUSIONS

Conclusions

- Sensors are the “eyes” of embedded vision systems
- Improvements in sensor functionality, performance, integration, cost and energy efficiency are helping to enable the proliferation of embedded vision
- Innovation in sensors is accelerating, fueled by high-volume application such as mobile devices and video games
- The choice of a sensor has a huge impact on the capabilities of the system, and on the required algorithms, processing power, bandwidth, etc.

Summary

Sensor		Typical Uses	Pros	Cons
CCD	2D	Science/Industrial	Sensitivity/IR/UV	High Cost
CMOS	2D	Consumer	Low Power	Noise/Sensitivity
Chip Camera	2D	Mobile Devices	Embedded	Cost
Structured Light	3D	Industrial CV	Simple Processing	Outdoor
Stereo	3D	Robotics	Low Cost	Big processing load
Time of Flight	3D	Robotics/Automotive	One Camera	Cost/Range/Outdoor

Next Up:

In tomorrow's presentation, we will introduce processors, the "brains" of an embedded vision system.

We'll explore the main types of processors used in embedded vision applications, and some of their key strengths and weaknesses.

Later in the week, we'll explore:

- Design tools and techniques for embedded vision
- Common building-block algorithms for embedded vision

RESOURCES

The *Embedded Vision Summit*
A Free Educational Event for Engineers—Boston, September 19th

Learn how to use the coolest new technology in the industry to create "machines that see"

- Technical presentations on sensors, processors, tools, and design techniques
- Keynotes by Prof. Rosalind Picard, MIT Media Lab and Gary Bradski, CEO, OpenCV Foundation
- Cool demonstrations and opportunities to meet with leading vision technology suppliers

Part of UBM Electronics' DESIGN East event

- DESIGN East also includes the Embedded Systems Conference, Sensors in Design, DesignMED, Android Summit, LED Summit, and exhibits

The Summit is free, but space is limited. To begin the registration process, send an email to summit@Embedded-Vision.com

For more info: www.embedded-vision.com/embedded-vision-summit

Selected Resources: The Embedded Vision Alliance

The Embedded Vision Alliance is an industry partnership to transform the electronics industry by inspiring and empowering engineers to design systems that see and understand

Free Resources from the Embedded Vision Alliance

The Embedded Vision Alliance web site, at www.Embedded-Vision.com covers embedded vision applications and technology, including interviews and demonstrations

The Embedded Vision Academy, a free service of the Alliance, offers free in-depth tutorial articles, video "chalk talks," code examples and discussion forums: www.EmbeddedVisionAcademy.com

The Embedded Vision Insights newsletter provides updates on new materials available on the Alliance website. Sign up at www.Embedded-Vision.com/user/register

Embedded vision technology and services companies interested in becoming sponsoring members of the Alliance may contact info@Embedded-Vision.com

Embedded Vision Insights
The Latest Developments on Designing Machines that See

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Selected Resources

- CCD/CMOS Sensors:
  - DALSA white paper, “Applications Set Imager Choices”
  - “Noise Sources in Bulk CMOS”, Kent H. Lundberg

What is BDTI?

BDTI is a group of engineers dedicated to helping the electronics industry effectively use embedded digital signal processing technology

BDTI performs hands-on, independent benchmarking and evaluation of chips, tools, algorithms, and other technologies

BDTI helps system designers implement their products through specialized engineering services

BDTI offers a wealth of free information for engineers

Additional Resources

BDTI's web site, www.BDTI.com, provides a variety of free information on processors used in vision applications.

BDTI's free "InsideDSP" email newsletter covers tools, chips, and other technologies for embedded vision and other DSP applications. Sign up at www.BDTI.com.