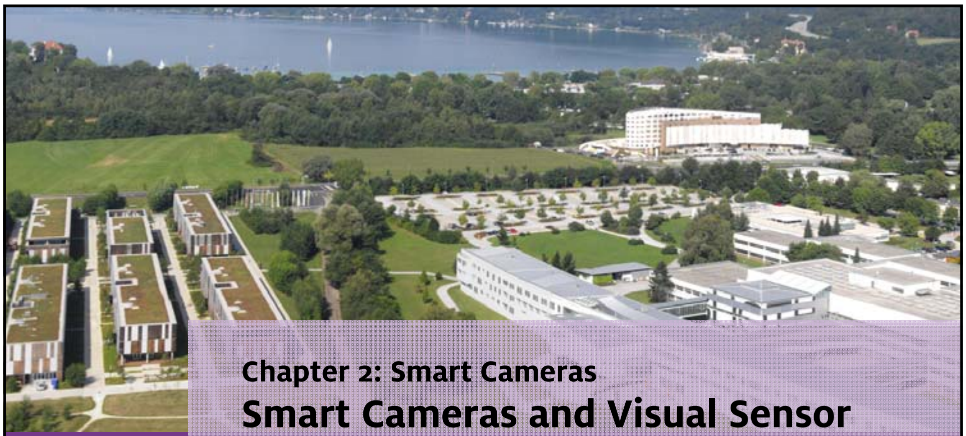

Chapter 2: Smart Cameras

Smart Cameras and Visual Sensor Networks

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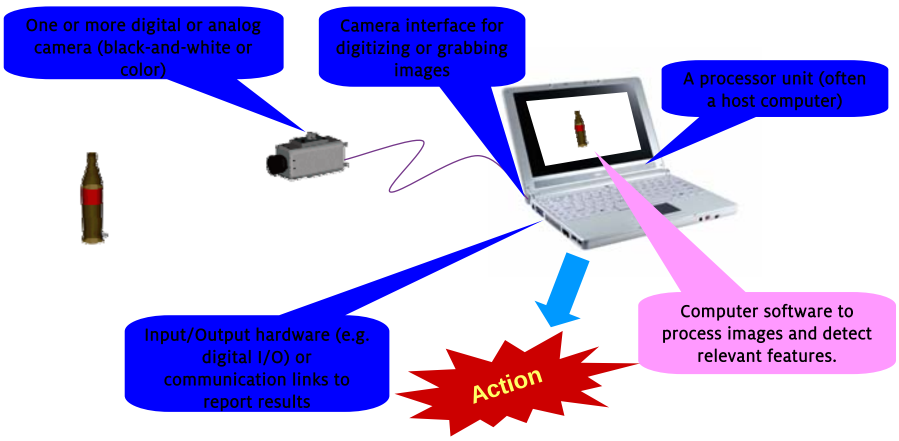
Agenda

Chapter 2: Smart Cameras

- Architecture of Smart Cameras
  - Sensing
  - Processing
  - Communicating
- Prototypes
  - Wired communication interface
  - Wireless communication interface

Architecture of Smart Cameras

A traditional Computer Vision System



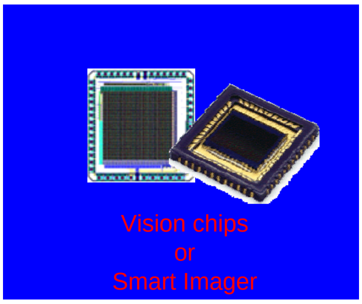
Integration as Embedded System

- Computer Vision Systems can be integrated at different levels

System-level

Example: surveillance,...

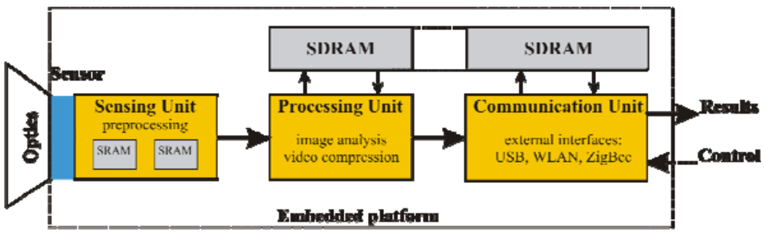
Chip-level



Example: optical mouse,...

Smart Camera Architecture

- Main components



[Rinner, Wolf. Introduction to Distributed Smart Cameras. Proc. IEEE, 96(10):1565–1575, 2008]

Sensing Unit

- Main objective: capture and efficiently provide image data for further processing
- „Transform light into digital data“
- Components
  - Optics
  - Sensor
  - Interface

CCD Sensors

- CCD imager consists of a large number of light-sensing elements arranged in one or two-dimensional array on a thin silicon substrate.
- The fundamental light-sensing unit of the CCD is a metal oxide semiconductor (MOS) capacitor operated as a photodiode and storage device

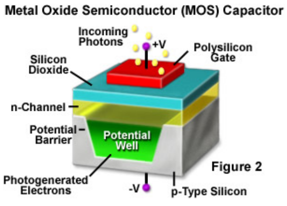


Figure 2

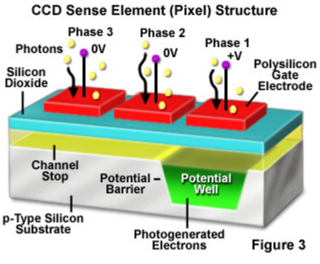


Figure 3

CCD Sensor

- Photons release electrons (photoelectric effect)
- Electrons emitted by photosensor during capture stored in a potential well
- Electrons passed into the shift register for read out
- Bucket-brigade analogy

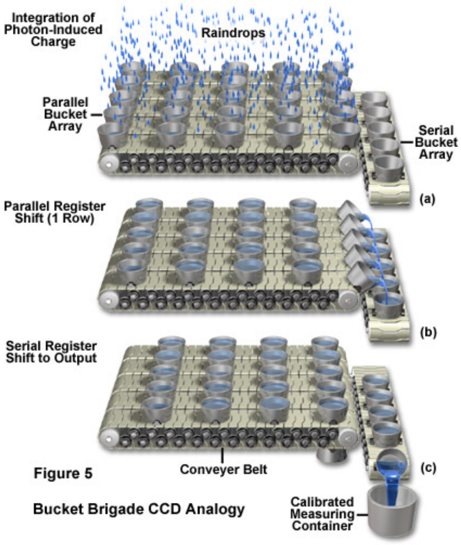
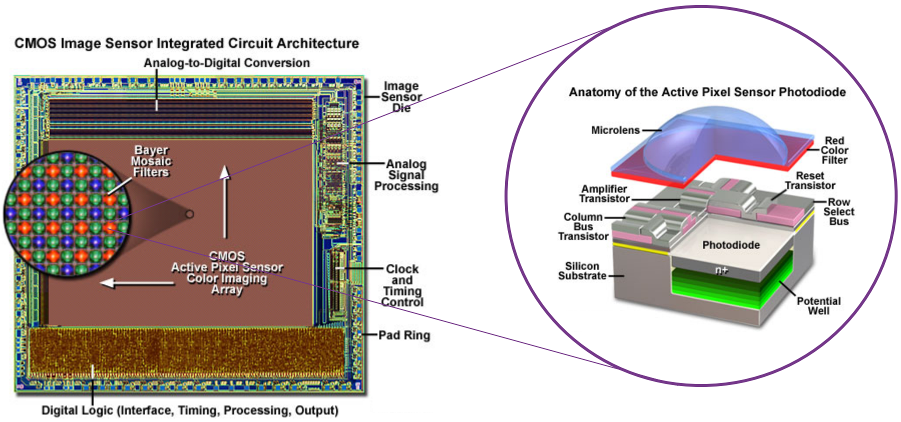


Figure 5

Bucket Brigade CCD Analogy

CMOS Sensor

- CMOS sensors are built by (an array) of active pixel sensors and integrate various control and processing functions



CCD vs. CMOS Sensors

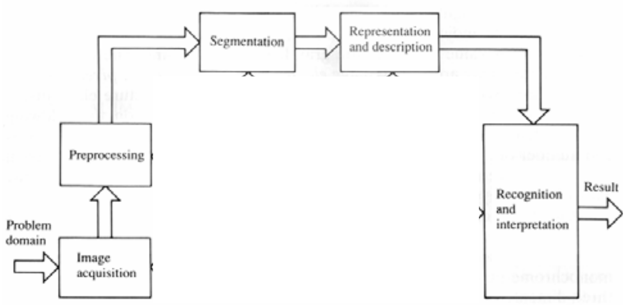
	CCD	CMOS standard
Noise	Low	Moderate
Cost	High (dedicated process)	Low (volume)
Output	Serial	Random access
*Power needed**	High	Low (CMOS)
Speed	Moderate to high	Higher
Photo detection	MOS Capacity	Transistors
Clocks	Multiple	Single
Integration	Hard	Easy

*A typical CCDs consumes 2 to 5W of power, a CMOS chip typically 20mW to 50mW

Source : http://www.dalsa.com/shared/content/Photonics_Spectra_CCDvsCMOS_Litwiller.pdf

Processing Unit

- Main objective: extract the relevant information from the (huge amount of) image data
- Huge data extraction: „From MegaBytes to bits“
- Typical image pipeline



[Gonzalez, Woods. Digital Image Processing, Prentice Hall]

Architectural Issues

- Embedded processing of image pipeline
  - low-level operations (regular patterns on many pixels)
  - high-level analysis (irregular on few objects)
- Memory often bottleneck in streaming applications
  - capacity
  - bandwidth
  - standard techniques (caches etc.) may not be sufficient
- Processing platforms
  - FPGAs, DSPs, specialized processors (SIMD)
  - microcontroller, g-p processors
- Power consumption!

Processing Performance

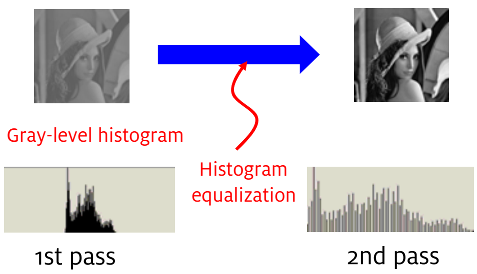
- Parallel processing is a (the) main source for performance improvements
- Execute processing threads in parallel on multiple cores or on dedicated hardware
- Mostly high data parallelism in (low-level) image processing
- Different data access patterns and dependencies in images space

Data Dependency in Image Space

- Independent pixel processing
  - The output pixels depends on single input pixel; single pass over image is sufficient to compute output
  - Examples
    - Lookup Table
    - Gray-level or color thresholding
    - Color space conversion
    - Brightness correction
    - Arithmetic operations
    - Logic operations

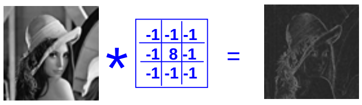
Data Dependency in Image Space (2)

- Multipass pixel processing
  - The output pixels depends on single input pixel; but multiple passes over image are necessary to compute output
  - Examples
    - Compute Statistics (Min, Max, Average, Std Devation etc.)
    - Histogram equalization
    - Hough transform



Data Dependency in Image Space (3)

- Fixed size block access
  - The output pixels depends on known block of input pixels
  - Examples
    - Morphology
    - Convolution, filtering
    - Wavelets
    - Feature tracking (KLT tracker, SAD, SSD,….)



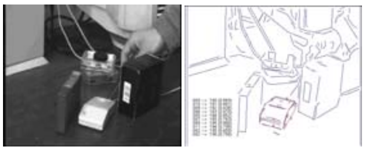
Data Dependency in Image Space (4)

- Data independent, global access
  - The output pixels depends on pixels from all over the input; the pattern is known
  - Examples
    - Viola-Jones
    - Warping or remapping for distortion correction

Tracking of deformable object

Data Dependency in Image Space (5)

- Data dependent, random access
  - The output pixels depends on pixels from all over the input; the pattern is not known (depends on data)
  - Examples
    - Dynamic vision
    - Contour finding, flood fill

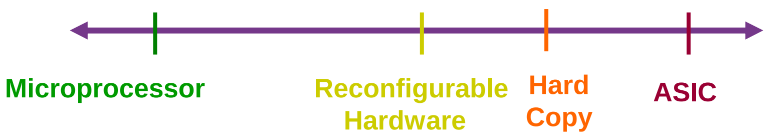


Tracking of segmented object based on contour finding

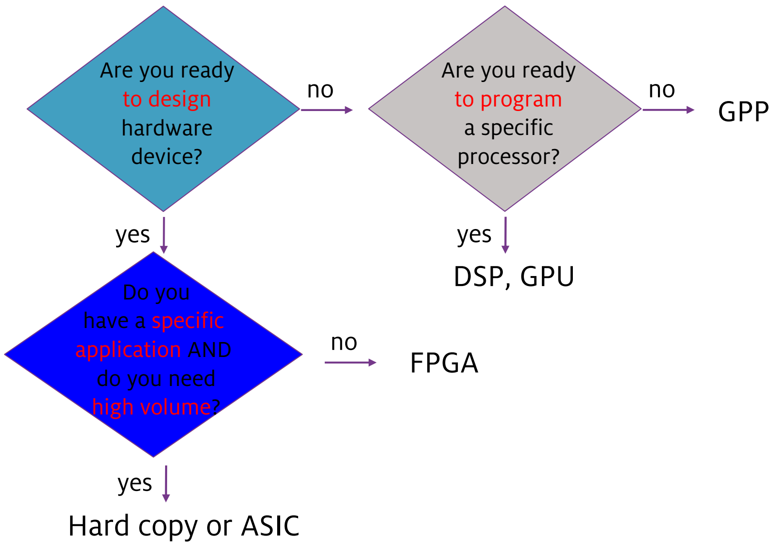
Only the motion parts are processed

Embedded Computing Devices

- Alternative platforms
  - Full custom ASIC
  - Reconfigurable HW (FPGAs, CPLDs)
  - Signal processors (DSP)
  - Graphic processors (GPU)
  - General-purpose processors
- Implementation spectrum
  - Flexibility vs. performance



Design considerations



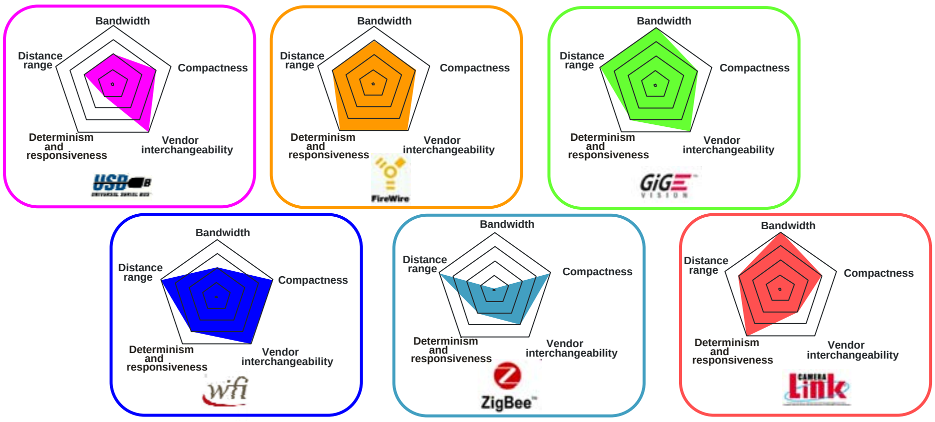
Communication Unit

- Wired communication protocols
  - USB 2.0 (480 Mbit/s)
  - FireWire or IEEE 1394a/b (400/800 Mbit/s)
  - Camera Link (2.04/4.08/5.44 Mbit/s)
  - Ethernet, GigE (10/100 Mbit/s, 1 Gbit/s)
- Wireless communication protocols
  - WiFi 802.11b/g (11/54 Mbit/s)
  - Bluetooth (1 Mbit/s)
  - ZigBee (IEEE 802.15.4) (250 kbit/s)
- Other issues
  - Streaming of raw data necessary
  - Power supply (e.g., Power over Ethernet)

Taxonomy of Communication units

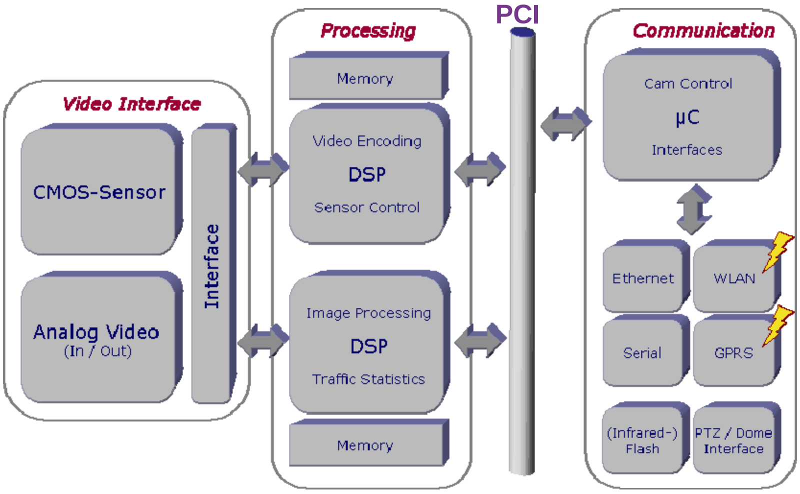
Communication channel can be classified according to 5 factors (not exhaustive!):

- Bandwidth, Distance range, Compactness, Determinism and Responsiveness, Vendor interchangeability



Prototypes

Scalable SmartCam Architecture



[Bramberger et al. Distributed Embedded Smart Cameras for Surveillance Applications. Computer 2006]

SmartCam Prototypes

- 1. generation (single DSP)
  - COTS (NVDK, Ateme)
- 2. generation (multi-DSP & processor)
  - COTS (Intel baseboard, NVDKs)
  - 3 variations (different host processors)
    XScale PXA, XScale IXP, P4M
- 3. generation
  - PCB (10 x 25 cm), IXP+C6415+C6455
  - Spartan II for sensor interface&preprocessing

(Selected) Smart Camera Systems

System	Year	Platform	Distribution/Proc.	Autonomy
[Moorhead&Binni]	1999	ASIC	local	static
VISoc [Albani]	2002	SOC	local	static
[Wolf et al.]	2002	DSP (PC)	local	static
[Bramberger&Rinner]	2004	DSP	local	rem. conf.
[Dias&Berry]	2007	FPGA	local	active vis.
[Bauer]	2007	DSP	local	static
GestureCam [Shi]	2007	FPGA	local	static
[Bramberger et al.]	2006	multi-DSP	cooper. tracking	dyn. conf.
[Micheloni et al.]	2005	(PC)	MC-tracking	PTZ
[Fleck&Strasser]	2007	PowerPC	MC-tracking	static

Characteristics of early Smart Cameras

- Some integration of sensing and processing
- Single cameras
- Perform low-level image processing
- Limited networking (basically no networking in the beginning)
- DSPs and FPGAs as processing platforms

Motes as new Camera Platforms

- Prototypes differ in various aspects
  - computing power, energy consumption
  - Network interfaces
  - optics and sensors



WiCa/NXP (Xetal SIMD) 50 GOPS @ 600mWatt | CMUcam3 (ARM7) 60 MIPS @ 650mW | CITRIC (PXA270) 660 MIPS @ 970mW

- Platforms for Visual Sensor Networks

(Selected) Smart Camera "Sensors"

System	Year	Platform	Distribution	Radio
Cyclops [Rahimi]	2005	ATmega128	coll. tracking	via Mica2
CMUcam 3 [Rowe]	2007	ARM7	local proc.	-
Meerkats [Margi]	2006	StrongARM	coll. tracking	ext. 802.11b
MeshEye [Hengstler]	2006	ARM7	local	via CC2420
WiCa [Kleihorst]	2006	Xetal (SIMD)	coll. gesture rec	via CC2420
CITRIC [Chen]	2008	PXA	tracking	via Tmote

More details

[Akyildiz et al. Wireless Multimedia Sensor Networks: Applications and Testbeds PIEEE 2008]
[Rinner et al. The Evolution from Single to Pervasive Smart Cameras. ICDSC 2008]

Smart Phones as Smart Cameras

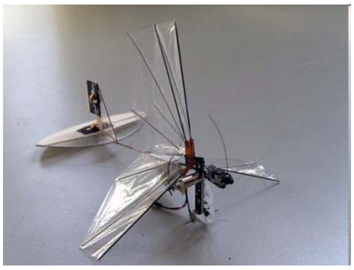
- Attractive platform
  - Huge amount of deployed cameras
  - Enriched with other sensors
  - Inherent networking
  - Reasonable processing power
- Dedicated mobile camera
- Exciting applications in AR, tracking, tagging

[Wagner et al. Real-Time Detection and Tracking for Augmented Reality on Mobile Phones. IEEE TVCG 2010]

Other camera platforms

- PillCam COLON by Given Imaging
  [www.givenimaging.com]

- DelFly Micro UAV (TU Delft)
  [www.delfly.nl]



Summary

- Smart Cameras combine sensing, processing and communication on a single embedded device
- Smart Cameras integrate a computer vision system and can be (easily) programmed/configured
- Smart Camera have limited resources
- Prototypes
  - Wired communication interfaces & external power supplies
  - Wireless interfaces & battery powered (cp. camera motes)

Tutorial Agenda

1. Introduction
2. Smart cameras
   - Architecture of Smart Cameras
   - Prototypes
3. Visual Sensor Networks
   - Advantages & Challenges
   - Characteristics of Visual Sensor Networks
   - Research Directions
4. Applications
   - Security- and privacy-awareness in Smart Camera Networks
   - Aerial Visual Sensor Networks
5. Conclusion