The Evolution from Single to Pervasive Smart Cameras

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Ubiquitous and Pervasive Cameras

- We observe a revolution in cameras
  - From cameras as boxes delivering images
  - to cameras as spatially distributed that generate data and events
  - making them pervasive in everyday life
- This revolution is driven by advances in lenses, image sensors, processors, networks etc.
- Distributed smart cameras represent one aspect of that revolution

Smart Camera Progress

- Dramatic progress in smart camera development
  - 1980s: sensing integrated with low-level processing
  - 1990s: first commercial „intelligent“ cameras
  - 2000s: smart camera networks, visual sensor networks …
- Major evolution paths of smart camera research
  - Integration of sensing and processing:
    single smart cameras (SSC)
  - Collaborative and distributed sensing:
    distributed smart cameras (DSC)
  - Adaptivity, autonomy and user-orientation:
    pervasive smart cameras (PSC)

Objectives

- Analyze and classify smart camera research
  - Review SC research/platforms
  - Classify SC based on a taxonomy
  - Identify the design space
- Elaborate the vision of pervasive smart cameras
  - Identify application scenarios
  - Discuss research challenges

Taxonomy of Smart Camera Systems

- Platform capabilities
  - Capabilities of image sensor, processing unit and communication
  - Power requirements
- Degree of distributed processing
  - Multiple streams are analyzed independently
  - Multiple streams are analyzed jointly at central server
  - Distributed and collaborative analysis
- System autonomy
  - Deployment
  - Configuration
  - Mobility

Single Smart Cameras

- Joint sensing and processing
  - Wide variety of on-board processing: filtering to object detection
  - Typical platform: DSP and/or FPGA
- Selected examples

System	Sensor	CPU	Comments
Moorhead et al. (1999)	CMOS	Custom logic	SoC
Albani (2002)	CMOS	32-bit RISC	SoC
Wolf (2002)	NTSC	PC & Trimedia	gesture recogn.
Bramberger (2004)	CMOS (VGA)	DSP (C64x)	BG modelling
Arth (2006)	PAL	DSP (C64x)	multiple streams
Bauer (2007)	neuromorp.	DSP (Blackfin)	traffic monitor.
Dias (2007)	CMOS (4MP)	FPGA (Stratix)	active vision

Distributed Smart Cameras

- Process data in camera network
  - Distribution of control: central vs. peer-to-peer processing
  - Distribution of data: static vs. ad-hoc
  - Platform: often “emulated” smart cameras
  - Application: tracking, gesture/activity recognition
- Selected examples

System	Platform	Distrib. proc.	Description
Bramberger (2006)	ARM & DSPs	m-c tracking	peer-to-peer
Fleck (2006)	PowerPC	m-c tracking	central
Velipasalar (2006)	PC	m-c tracking	peer-to-peer
Aghajan (2007)	PC	gesture rec.	fusion

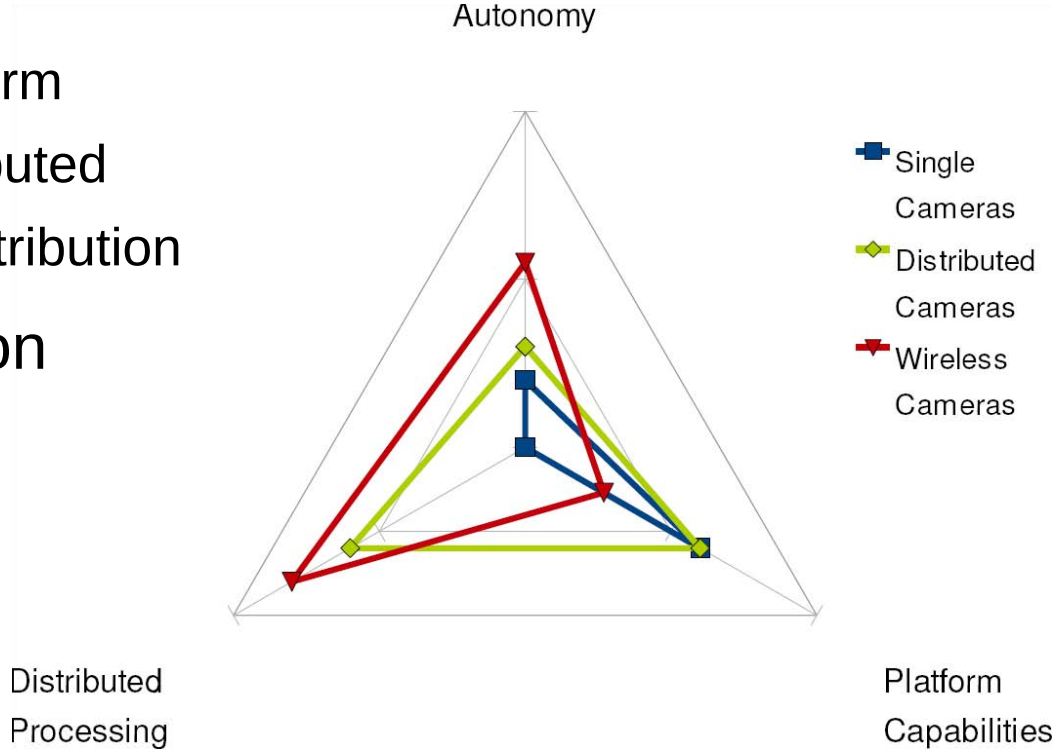
Smart Cameras for Sensor Networks

- Sensing, image processing & wireless communication
  - Restricted resources (computation, communication, space …)
  - Power consumption major concern
  - Platform: controller-based (ARM etc.); communication module off-board
- Selected examples

System	Platform	Communicat.	Comment
CMUCam 3 (2007)	ARM7	802.15.4	external comm.
Cyclops (2005)	ATmega128	802.15.4	external comm.
Meerkats (2006)	StrongARM	802.11b	
MeshEye (2007)	ARM7	802.15.4	
WiCa (2006)	Xetal (SIMD)	802.15.4	

One view of smart camera platforms

- Design space based on the 3 dimensions of our taxonomy
- Depending on application we can identify different "clusters"
  - SSC focus on platform
  - DSC "evenly" distributed
  - PSC autonomy&distribution
- No rigid classification



Hardware Challenges

- Vision: “Continuous progress in sensor, processor and communication technology enables DSC to solve complex CV applications in real-time”
- We face “typical” challenges of embedded systems
  - Power-awareness
  - Integration and size
  - Hardware-software gap
- What about mobile phones?

(System-)Software Challenges

- Vision: “Our SC are easy to program. We can reuse code on the different platforms to develop scalable applications.”
- Diverse and heterogeneous platforms hinder application development
- Some “standard” system-level software / middleware
  - Abstracts underlying hardware and network
  - Provides various services for deployment and operation
- Methods and tools for development
- Modeling the distributed application

Adaptation/Autonomy Challenges

- Vision: “DSC are deployed in highly dynamic environments (observed scene, camera network and functionality) and achieve robust results”
- Autonomy
  - Camera “placement” and configuration
  - Calibration and synchronization
  - Maintenance-free operation
- Adaptivity
  - Scene adaptivity

Collaboration Challenges

- Vision: “DSC perform distributed sensing and processing in an ad-hoc/dynamic manner.”
- Distribution of control and data
  - Protocols
  - Stronger requirements than typically in sensor networks
- Distributed analysis
  - Novel algorithms

User-oriented Challenges

- Vision: “DSC can be easily deployed, securely operated and provide various services.”
- Privacy and security
  - Processing in trusted cameras
- Integration and interaction
- Novel applications
  - Beyond surveillance and home-care
  - Entertainment, machine vision, medical,…

Conclusion

- Analysis of about 20 platforms classified in SSC, DSC and smart cameras in sensor networks
- Current SC platforms provide sophisticated HW but lack in system autonomy and offer only limited degree of distribution.
- Comparison is difficult due to lack of common taxonomy, test data, and (benchmark) applications.
- We face several challenges until we reach a comprehensive PSC system.
- Is there any killer application for pervasive smart cameras?

Links and Further Information

- Pervasive Computing Group, Klagenfurt University
  http://pervasive.uni-klu.ac.at
- Embedded Systems Lab, GaTech
  http://www.ece.gatech.edu/research/labs/esl/esl-overview.html
- Special issue on “Distributed Smart Cameras”
  Proceedings of the IEEE
  October 2008