PECCS 2011

Pervasive Smart Cameras

ALPEN-ADRIA UNIVERSITÄT
KLAGENFURT | WIEN GRAZ

FAKULTÄT FÜR TECHNISCHE WISSENSCHAFTEN

Institut für Vernetzte und Eingebettete Systeme

Bernhard Rinner

The Digital Universe

- Forecasts from a recent IDC report [1]
  - „The amount of digital information in the world will grow to almost 35 trillion GByte by 2020."
  - "The amount of digital information created already exceeds the available storage." By 2020 this storage gap grows to more than 60 %
  - „Cameras play a significant part for data creation"

[1] J. Gantz, D. Reisl. The Digital Universe Decade – Are You Ready?, May 2010 (IDC forecast report)

➢ Storing, analyzing, searching, protecting, etc. these huge amount of data becomes a real challenge

Ubiquitous Cameras

- We are surrounded by billions of cameras in public, private and business spaces
- Various well-known examples
  - Transportation
  - Security
  - Entertainment
  - …

- How to explore all the captured data ?

➢ Different view on camera(s) required, applies especially for pervasive computing

Revolution in Cameras

- Ongoing technological advances in
  - lenses
  - image sensors
  - onboard processing
  - networking
- transform camera as box delivering images into spatially distributed that generate data and events
- Huge amount of visual information is processed in a network of resource-limited embedded nodes in dynamic environment

➢ Make cameras smart, autonomous and collaborative

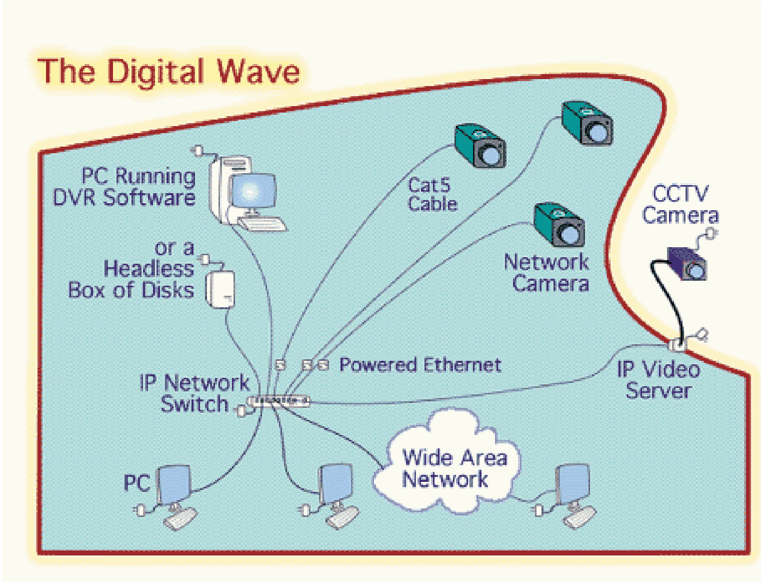
Agenda

- Smart Cameras
  - Introduction
  - Trends
- Selected Applications
  - Tracking
  - Configuration
  - Security & privacy
- Challenges
  - Research question
  - Conclusion

Smart Cameras

Traditional Camera Networks

- Cameras capture images/videos
- Raw or compressed data is streamed to central server
- Image data is displayed/archived/ analyzed at central point
- Data and energy is transferred over wired infrastructure



[Regazzoni et al. Special Issue on Video Communications, Processing and Understanding for Third Generation Surveillance Systems. Proc. IEEE. October 2001]

➢ Centralized and static architecture, heavy infrastructure required

Making Cameras smarter

- Smart cameras integrate sensing, processing and communication on single embedded device

Traditional Camera

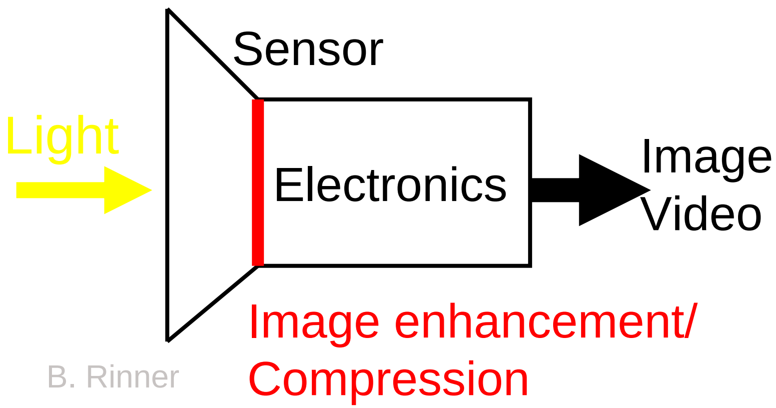
- Optics and sensor
- Electronics
- Interfaces

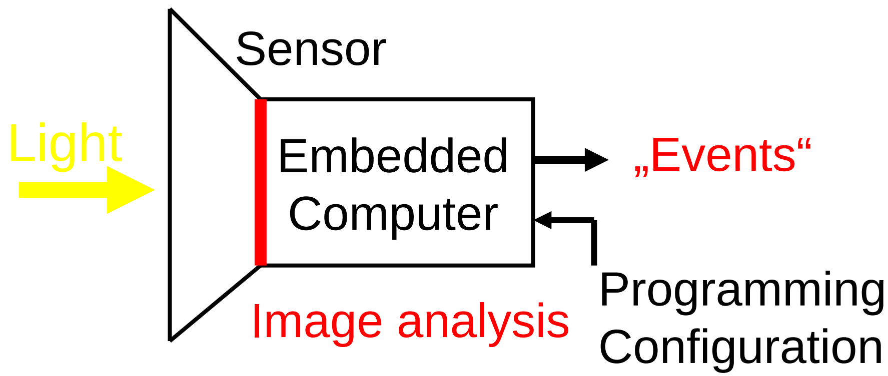
delivers data in form of (encoded) images or videos.

Smart Camera

- Optics and sensor
- Onboard computer
- Interfaces

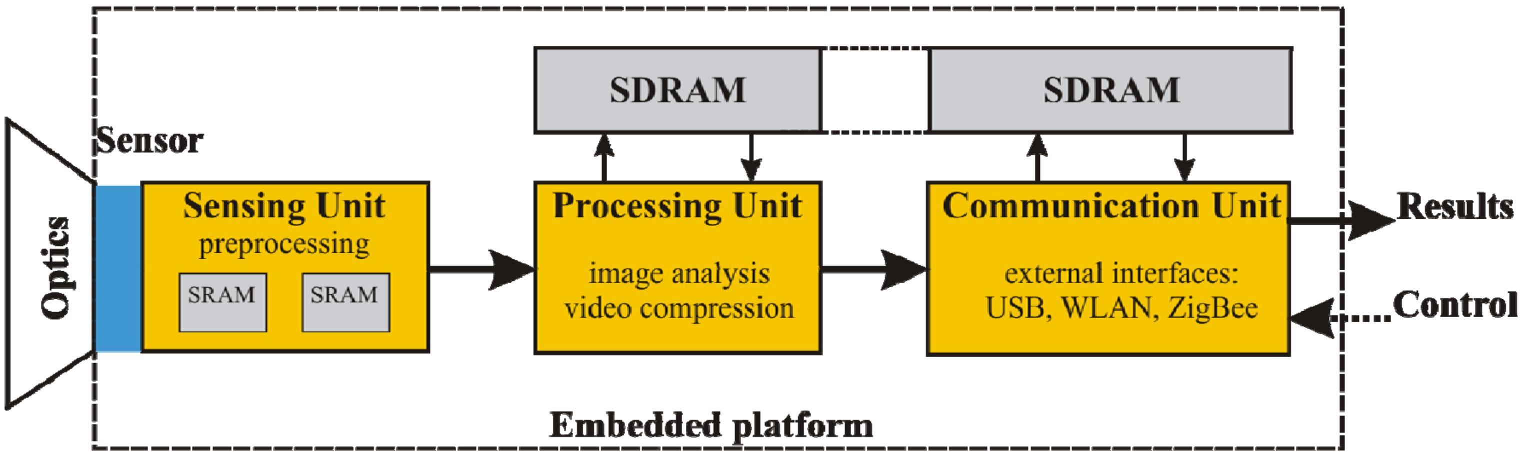
delivers abstracted image data and is configurable and programmable





Smart Camera Architecture

- Main components



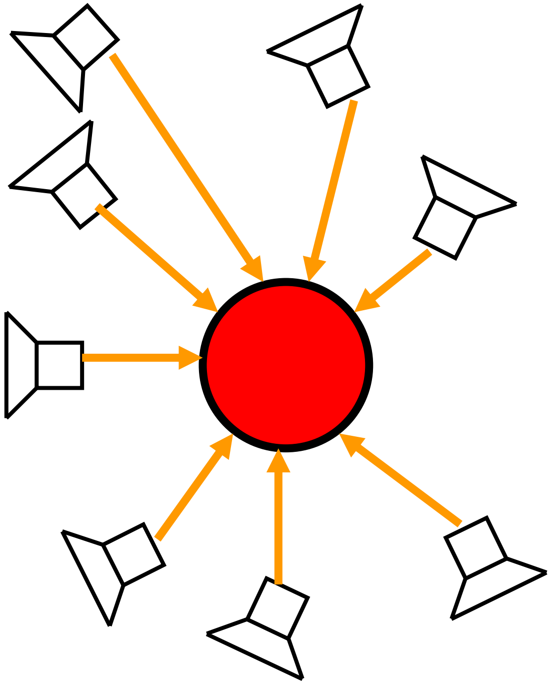
[Rinner, Wolf. Introduction to Distributed Smart Cameras. Proc. IEEE, 96(10):1565–1575, 2008]

Process data where it is captured

- Perform image and video analysis in real-time closely located at the sensor
- Deliver (only) abstracted events
- Reduce data transfer
  - From raw data to features or events
  - Example: tracking
- “Smart cameras look for important things”

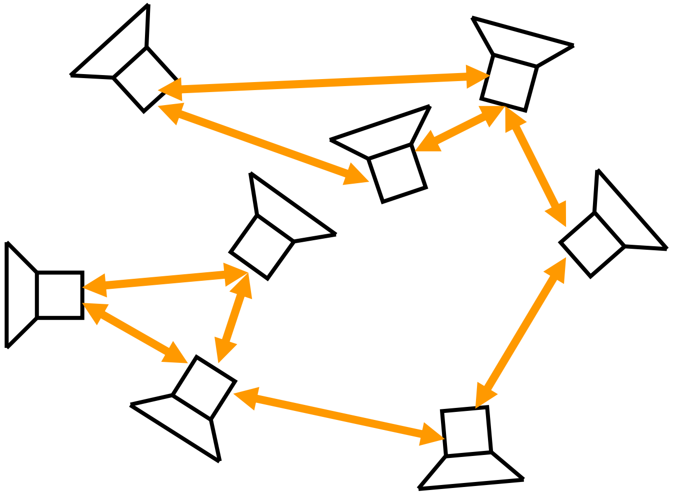
Collaborate spontaneously

Traditional Camera Networks



Cameras stream images/
videos to „server“

Smart Camera Networks



Cameras collaborate directly
(spontaneous, p2p, ad-hoc)

Perform advanced in-network analysis

- From data collection and streaming to dynamic collaboration
  - More demanding processing possible (eg., online learning)
  - Analysis may change depending on network state and environment
- Exploit heterogeneous sensors
  - Different cameras (static, PTZ, RGB/IR …) but also audio, laser etc.
  - Perform intra and/or inter node fusion
  - Synchronization and calibration necessary
- Deliver multimedia data at required QoS level
- Support autonomous operation at network level
  - Self-* methods

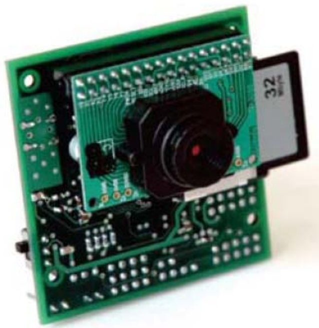
[Akyildiz et al. Wireless Multimedia Sensor Networks: Applications and Testbeds. Proc. IEEE, 2008]

Be aware of scarce Resources

- Major resource limitations
  - Processing power
  - Communication bandwidth
  - Onboard memory
  - Energy
- Various Prototypes

Rinner et al. (multi-DSP)
10 GOPS @ 10Watt

WiCa/NXP (Xetal SIMD)
50 GOPS @ 600mWatt



CMUcam3 (ARM7)
60 MIPS @ 650mW

CITRIC (PXA270)
660 MIPS @ 970mW

[Rinner et al. The Evolution from Single to Pervasive Smart Cameras. Proc. ICDSC 2008]

Why Networks of Smart Cameras?

- Scalability
  - No central server as bottleneck
- Real-time capabilities
  - Short round-trip times; “active vision”
- Reliability
  - High degree of redundancy
- Energy and Data distribution
  - Reduced requirements for infrastructure; easier deployment
- Sensor coverage
  - Many (cheap) sensors closer at “target”; improved SNR

➢ Compare with sensor networks

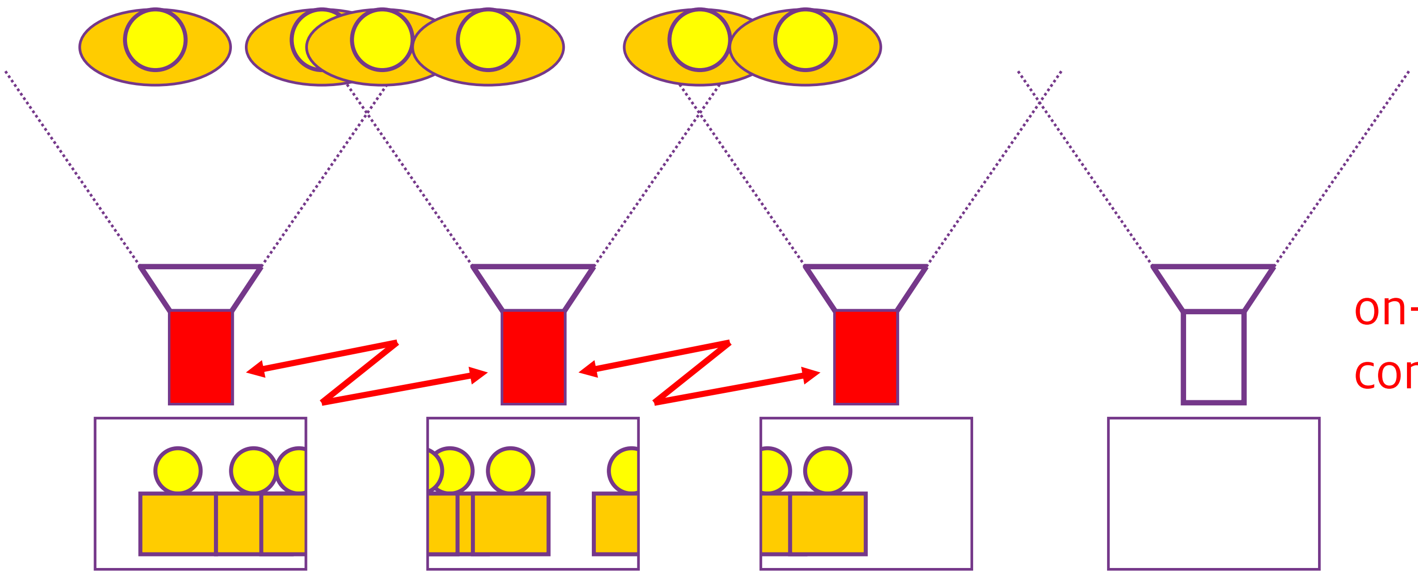
Selected Applications

Quest for Novel Pervasive Applications

- Some requirements
  - Easy deployment
  - Adaptive and scalable
  - Reactive/interactive
  - Secure- and privacy-aware
- Application domains
  - Distributed surveillance and security
  - Smart homes / smart buildings
  - Ambient intelligence
  - Human-computer interfaces
  - Mobile and robotic networks
  - Virtual reality systems
  - ...

Example 1: Multi-camera Tracking

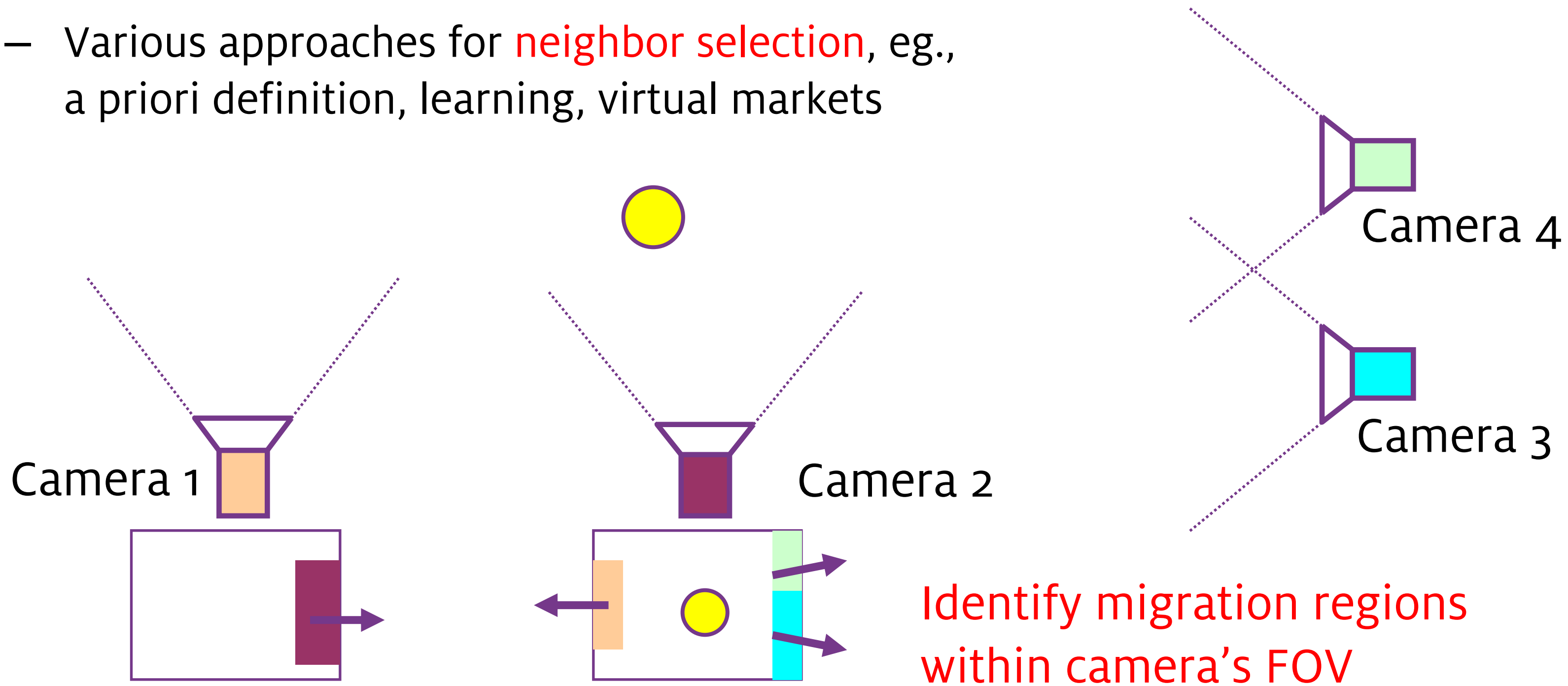
- Track mobile objects autonomously among multiple cameras



- Computation follows (physical) object
  - requires spontaneous communication; distributed control & data

Autonomous Migration of Processing

- Camera Handoff
  - Initialize object tracker on "neighboring" camera(s)
  - Similarity function for object re-detection
  - Various approaches for neighbor selection, eg., a priori definition, learning, virtual markets



Identify migration regions within camera's FOV

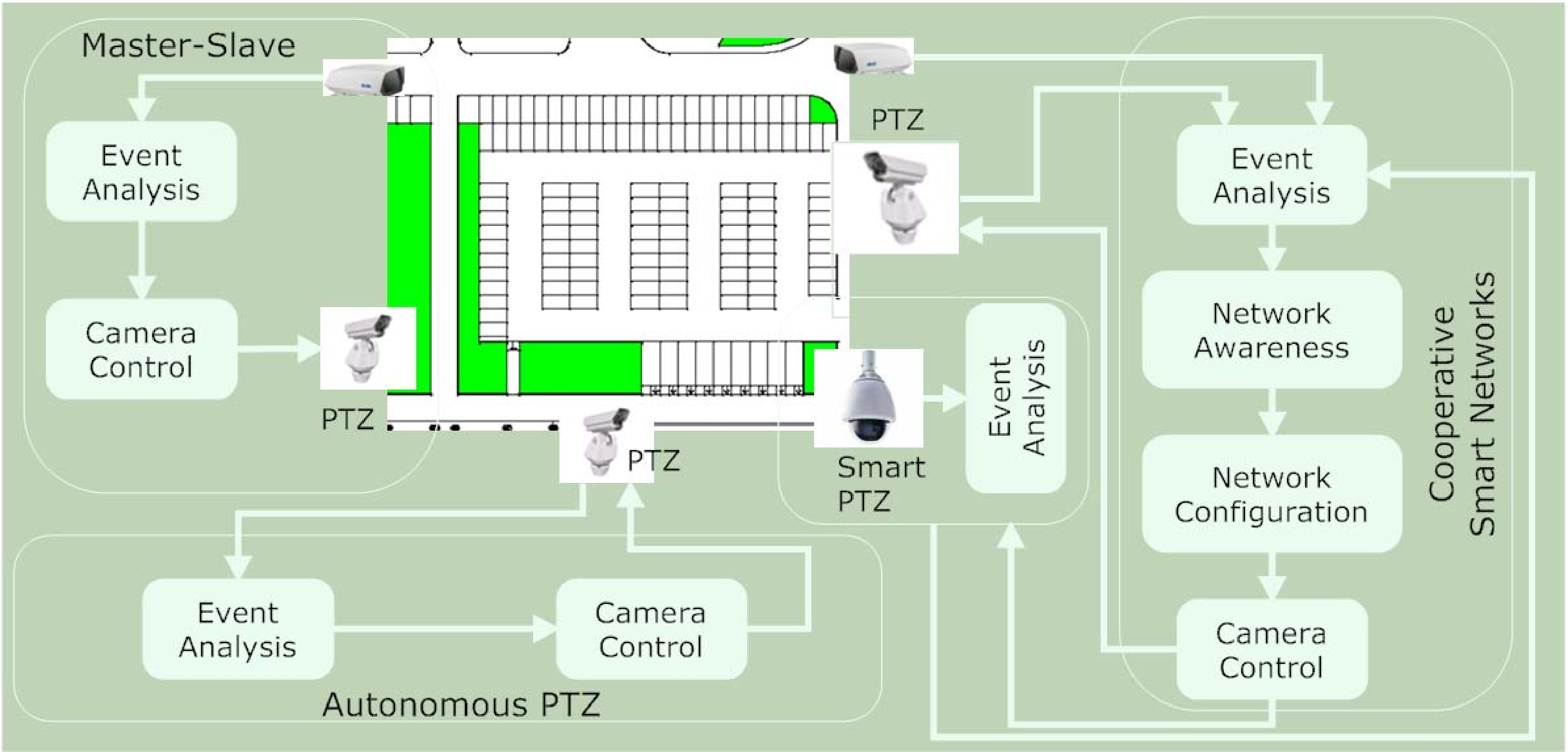
[Quaritsch, Kreuzthaler, Rinner, Bischof, Strobl. Autonomous Multicamera Tracking on Embedded Smart Cameras. EURASIP Journal on Embedded Systems. 2007]

Example 2: Mobile Camera Configuration

- Pan-Tilt-Zoom (PTZ) cameras allow to change their FOV
- Adapt coverage dynamically, eg., to
  - modify area of interest
  - follow targets
- Active visual sensor networks have to react in real-time
  - Estimate the current state (based on image analysis)
  - Compute the PTZ configuration (based on accurate modeling of 3D coverage)
  - Cooperate among cameras may be required for state estimation
- Comparison of different approaches

[Micheloni, Rinner, Foresti. Video Analysis in PTZ Camera Networks. IEEE Signal Processing Magazine. Sep. 2010]

Different forms of cooperation



Example 3: Security and Privacy

- System level approach addressing the following security issues in cameras:
  - Integrity: detect manipulation of image and video data
  - Authenticity: provide evidence about the origin of image and videos
  - Confidentiality: make sure that privacy sensitive image data cannot be accessed by an unauthorized party
  - Multi-level Access Control: support different abstraction levels and enforce access control for confidential data

- Considered attack types: only software attacks

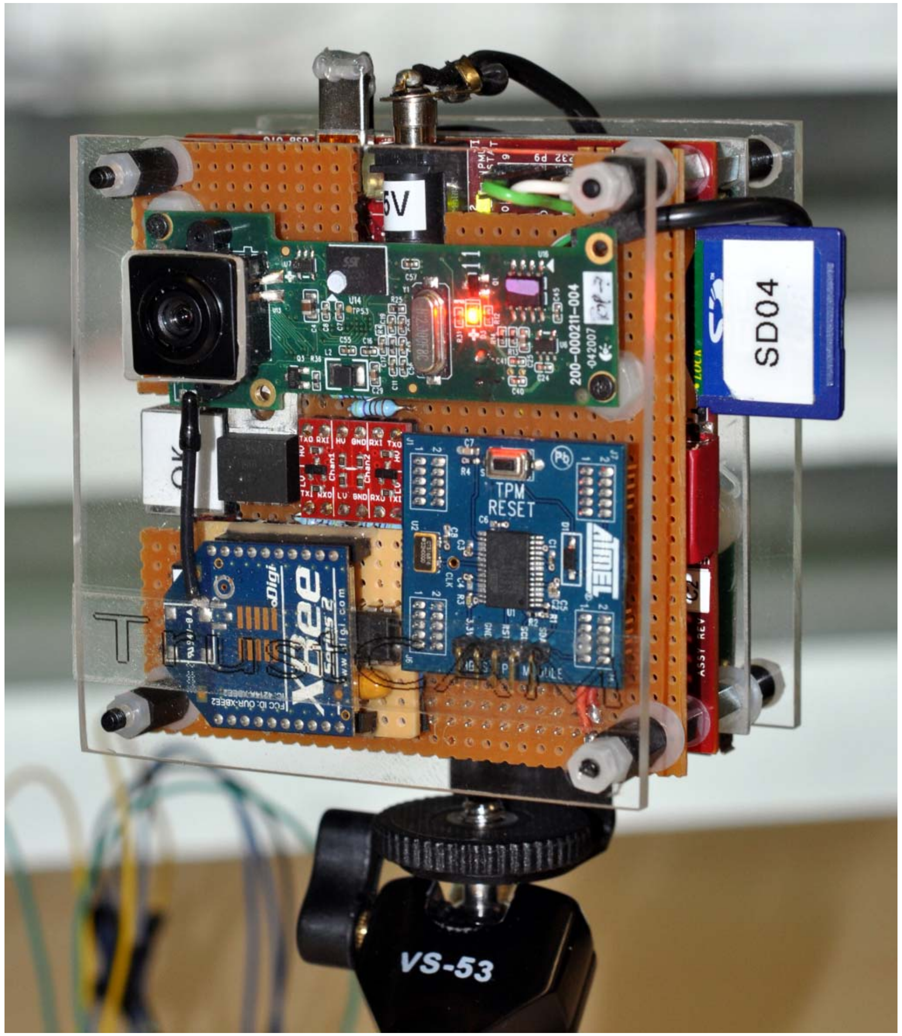
[Winkler, Rinner. Securing Embedded Smart Cameras with Trusted Computing. EURASIP Journal on Wireless Communications and Networking, 2011]

Our Approach: TrustCAM

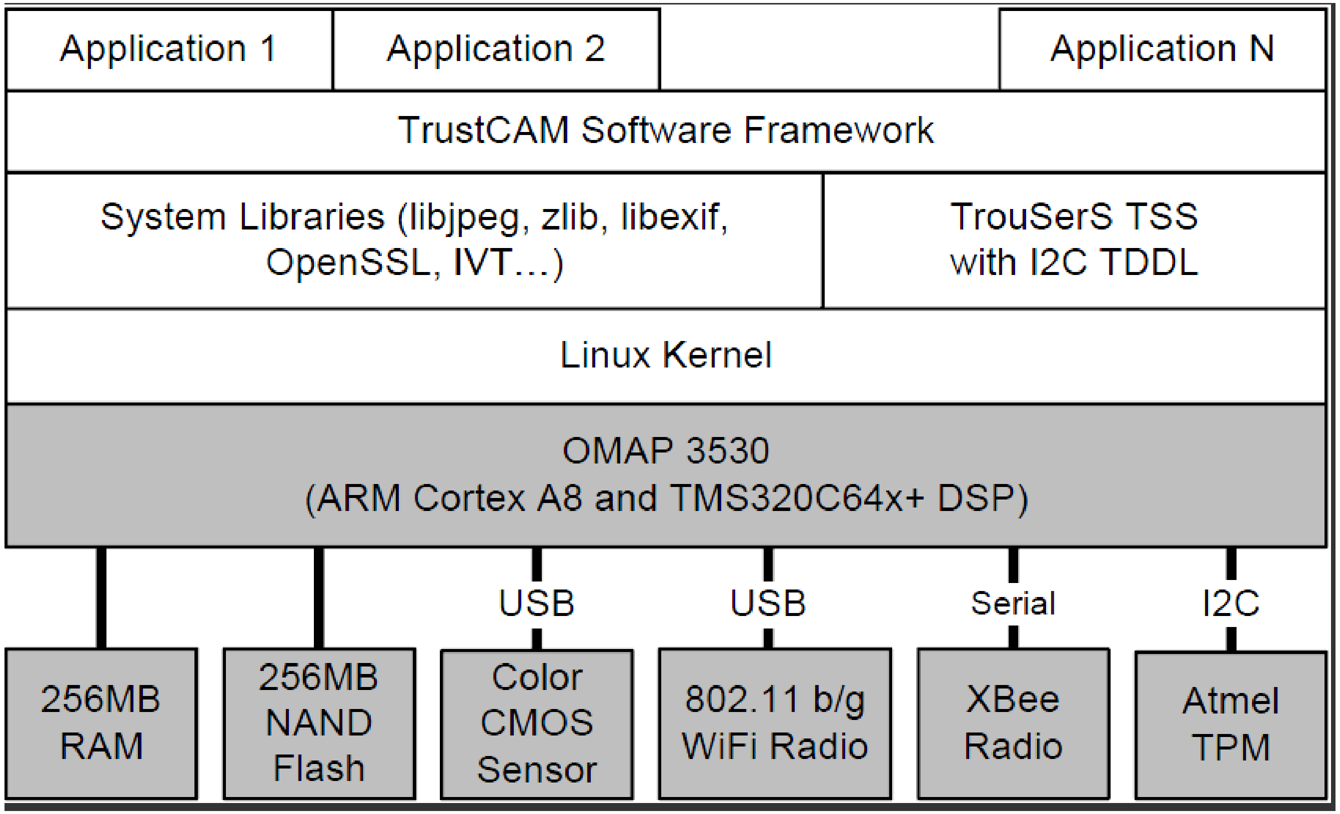
- We integrate Trusted Computing into camera prototype
- Trusted Computing (TC) is a hardware security solution based on microchip called Trusted Platform Module (TPM)
- Reasons for using TPMs:
  - Implement a well defined set of security functions
  - Public and well reviewed specification
  - Cheap and readily available
  - Hardware provides higher security guarantees than software
  - Using established technology is better than re-inventing the wheel (especially when doing security)
- Main challenge: TPMs are relatively slow
- Careful integration into camera is required

TrustCAM Prototype

- TI OMAP 3530 CPU:
  ARM @ 480MHz and
  DSP @ 430MHz
- 256MB RAM,
  SD-Card as mass storage
- VGA color image sensor
- wireless: 802.11b/g WiFi
  and 802.15.4 (XBee)
- LAN via USB
  (primarily used for debugging)
- Atmel hardware TPM
  on I2C bus



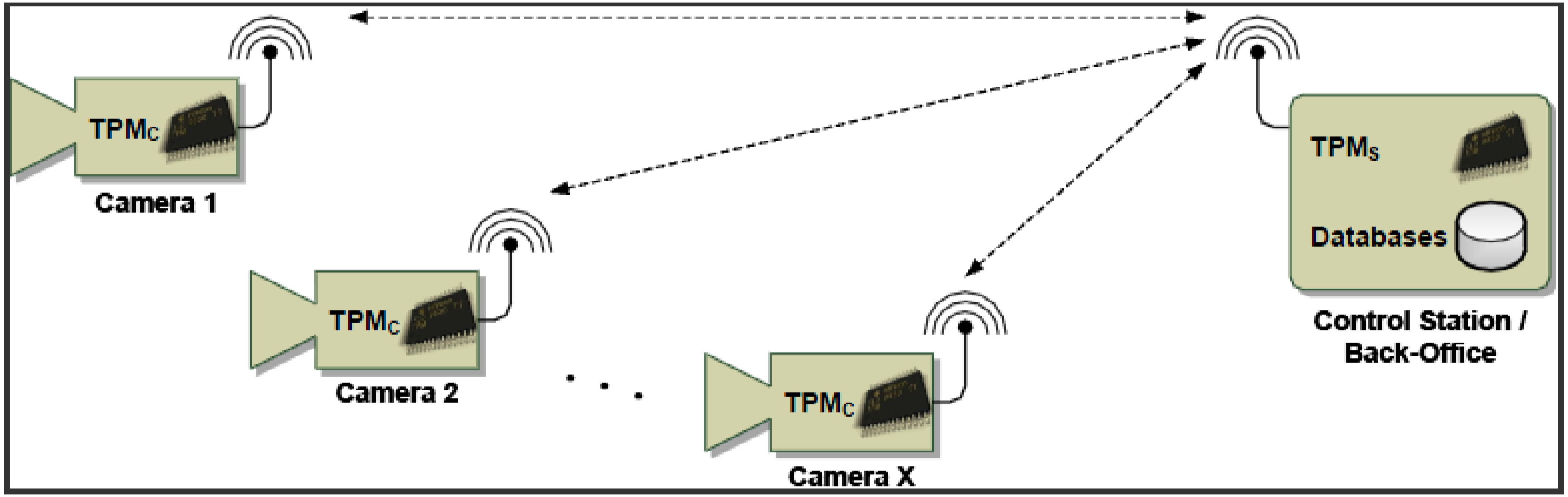
Hardware/Software Stack



- Embedded linux system (Angstrom based)
- Custom kernel with TPM integration
- Customized TrouSerS software stack for TPM access
- Component based application development framework

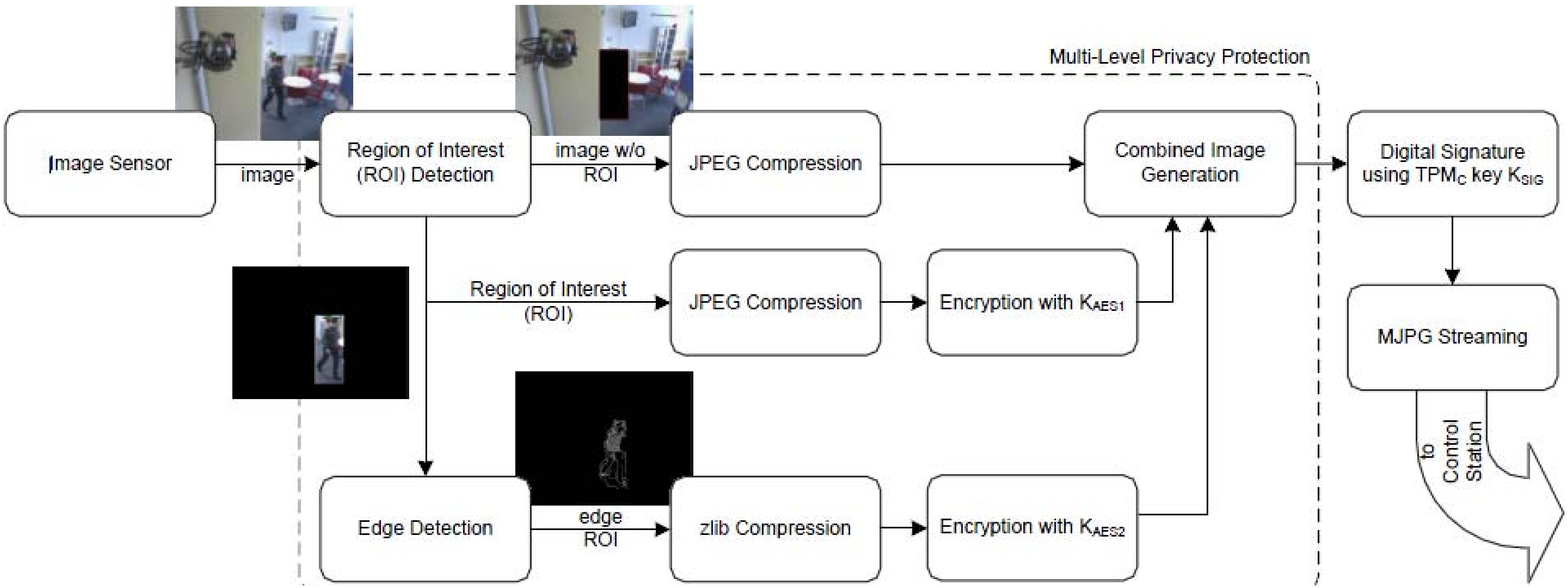
Architecture Overview

- Each Camera is equipped with a TPM called *TPM_C*



- Cameras are controlled from central back-office

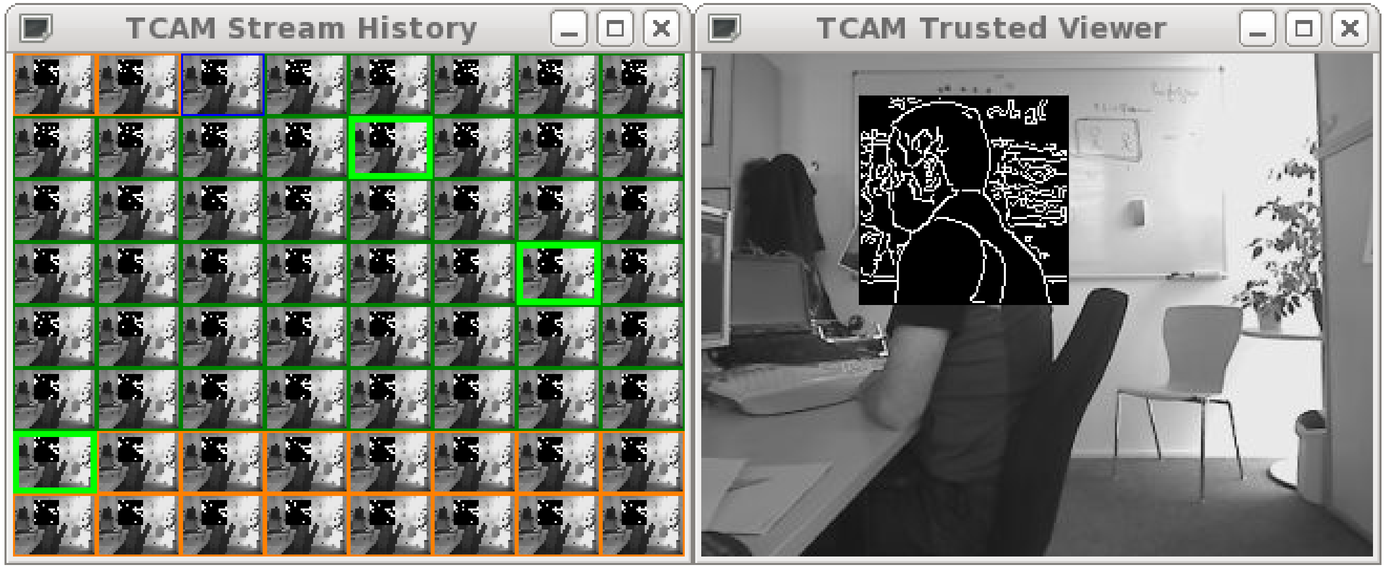
Multi-level security and privacy



Perform cryptographic operations onboard

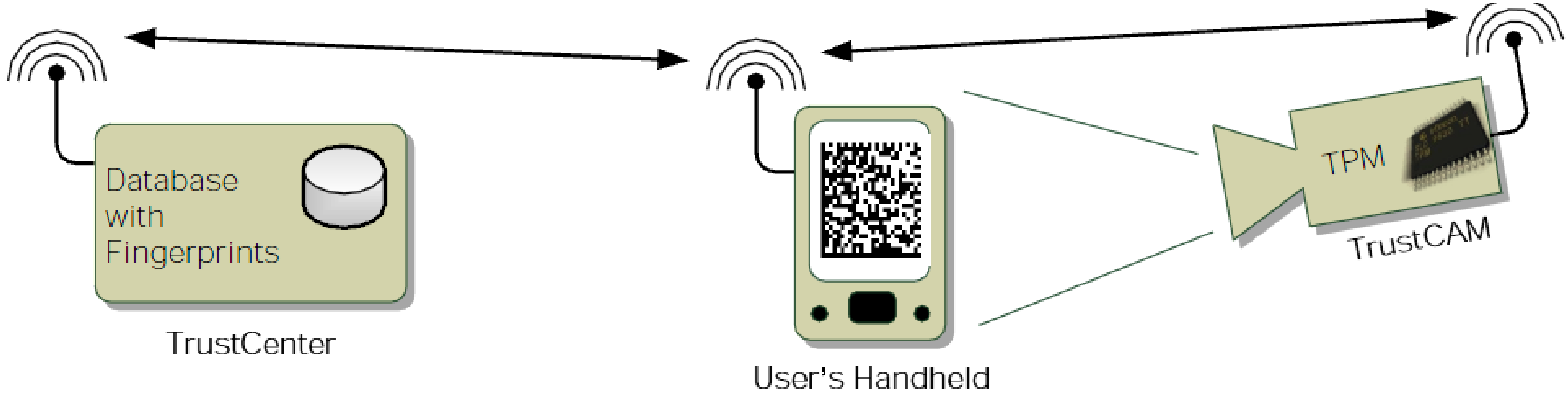
- Signing: integrity and authenticity
- Encryption: confidentiality and multi-level access control

Control Station



- Video viewer prototype
- Abstracted regions of interest
- Frame groups signatures embedded as custom EXIF data
- History: circular buffer with last 64 frames
  - Unverified frames: orange
  - Verified frames: dark green
  - Last frame of group: light green

Example 4: Authentic User Feedback



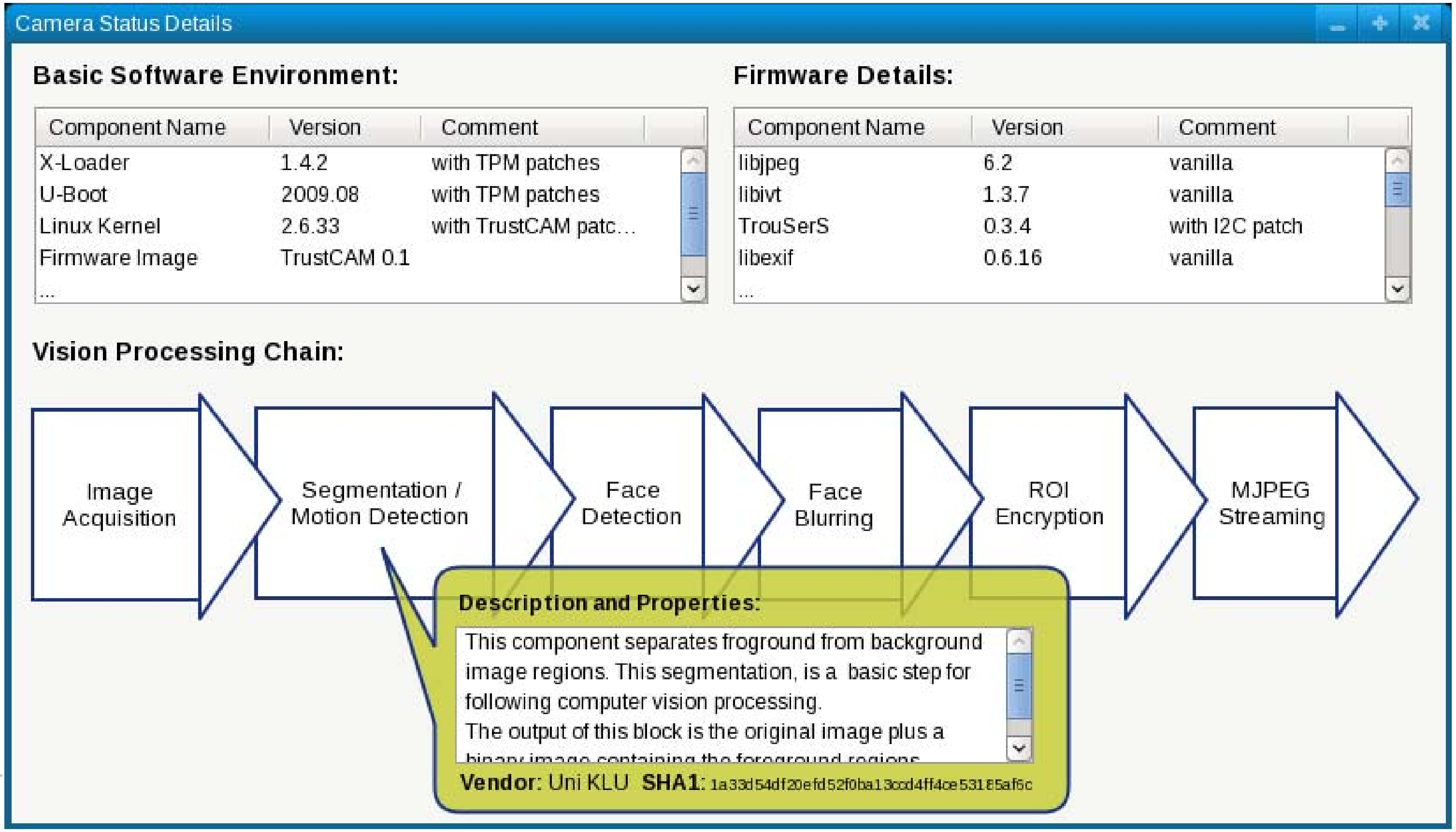
- How to certify what a camera is doing?
- An authentic communication channel between user & camera
  - Wireless channel is problematic
- Alternative: visual communication for device pairing
  - direct line of sight - attackers are easy to spot
  - intuitive way to select the intended camera
- Camera returns a list of hash sums of executed applications
- TrustCenter helps to translate hash sums into properties

User Feedback- Camera Selection

- User is equipped with a trusted handheld device
- 2D barcodes displayed on the user's handheld
- Barcode encodes attestation request and a challenge

Feedback on Mobile Device

- Provide detailed results available to users
- Show running vision processing blocks and their interactions
- Present description and check sums of blocks

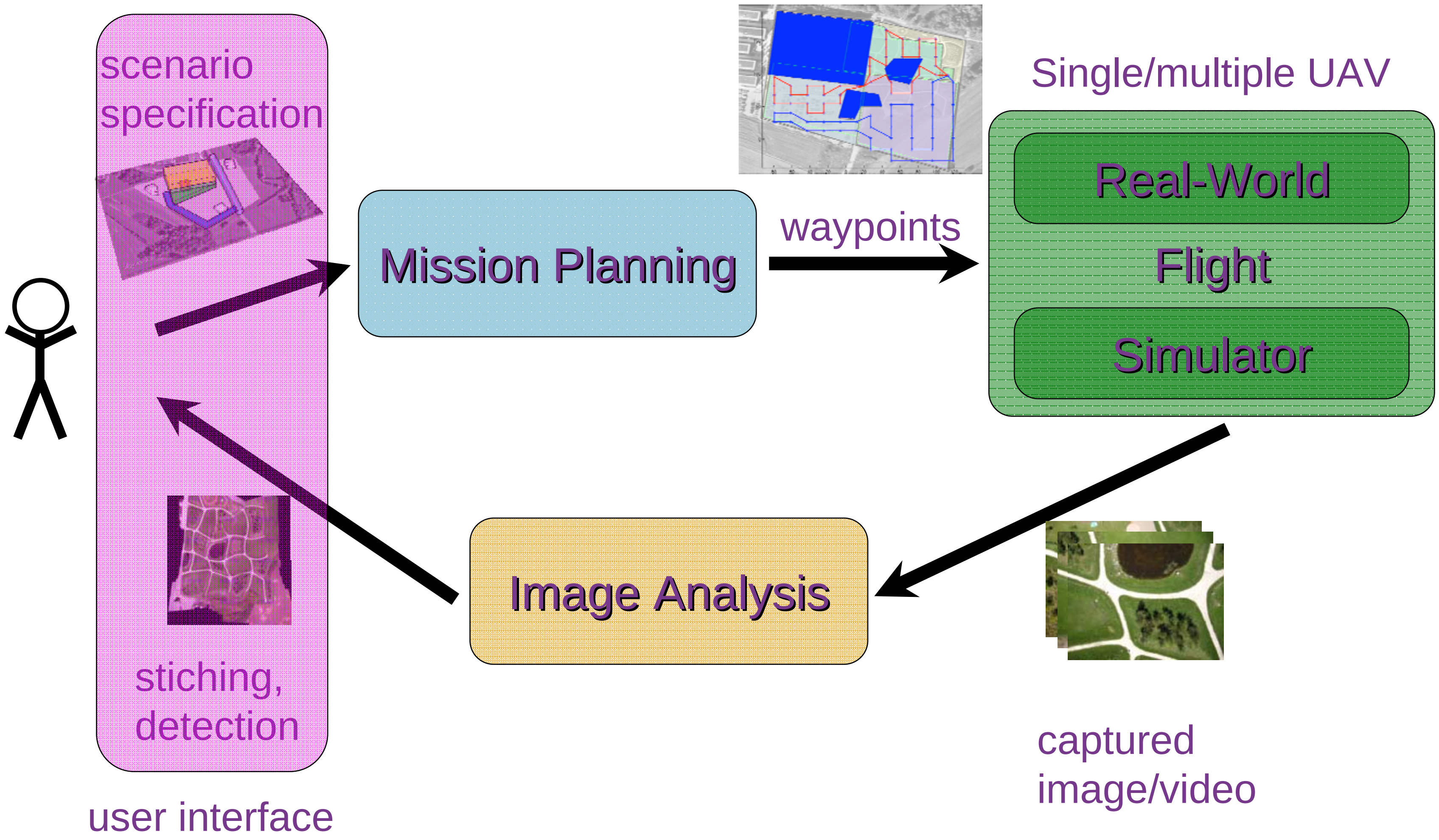


Example 5: Collaborative Aerial Cameras

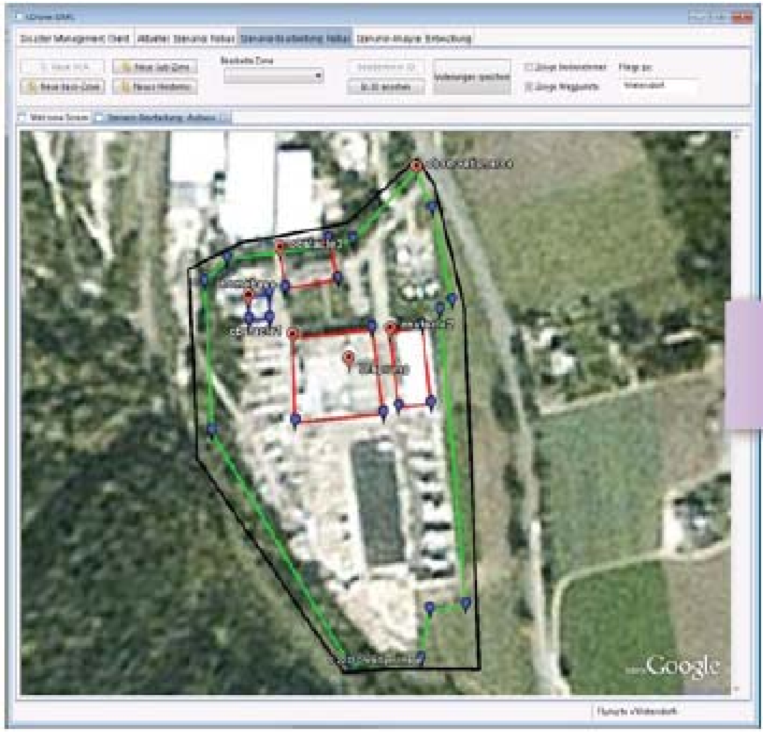
- Develop autonomous multi-UAV system for aerial reconnaissance
- Up-to-date aerial overview images are helpful in many situations:
  "Google Earth with up-to-date images in high resolution"

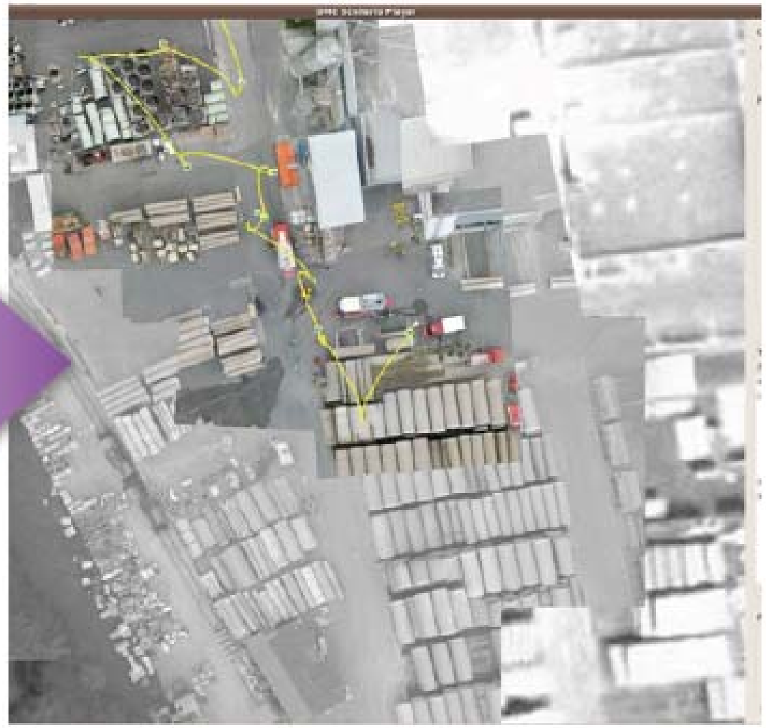
- Quadcopter platform with onboard sensors and computation
- GPS receiver for autonomous waypoint flights
- Limitations on payloads, flight time, weather conditions

Autonomous UAV Operation



User Interface





Define high-level tasks,
i.e., observation area

Real-time overview image
and execution status

http://pervasive.uni-klu.ac.at/cDrones [Videos]

Challenges

#1: Architecture

How to design resource-aware nodes and networks

- Low-power (high performance) camera nodes
  - Dedicated platforms: vision processors, PCBs, systems
  - Many examples: CITRIC, NXP
- Visual/Multimedia Sensor Networks
  - Topology and (multi-tier) architecture
  - Multi-radio communication
- Dynamic Power Management
  - For sensing, processing and communication

#2: Networking

How to process and transfer data in the network

- Ad hoc, p2p communication over wireless channels
  - Providing RT and QoS
  - Eventing and/or streaming
- Dynamic resource management
  - (local) computation, compression, communication, etc.
  - Degree of autonomy: dynamic, adaptive, self-organizing
  - Fault tolerance, scalability
  - Network-level software, middleware

#3: Deployment, Operation, Maintenance

Consider the entire life cycle of the camera network

- Development support for applications
  - Model/simulate the application (function, resources, QoS)
  - Reuse/exchange of software/libraries
  - Software updates, debugging etc.
- Autonomous calibration and scene adaption
  - Avoid manual procedures
  - Adapt to different scenes and settings
- Network configuration

#4: Distributed Sensing & Processing

Where to place sensors and analyze the data

- Sensor placement, calibration & selection
  - Optimization problem
  - Distributed approaches eg., consensus, game theory, multi-agent systems
- Compressive Sensing
- Collaborative data analysis
  - Multi-view, multi-temporal, multi-modal
  - Sensor fusion
- Online/real-time processing
  - Can not effort to store large amounts of data

#5: Mobility

How to exploit networks of mobile cameras

- Mobile cameras are ubiquitous
  - PTZ, vehicles, robotics etc.
  - Mobile phones
- Advanced vision algorithms
  - Ego motion, online calibration
  - Closed-loop control, active vision

#6: Usability

How to provide useful services to people

- Ease of deployment, maintenance
  - Self-* functionality
  - “Smart cameras for dumb people”
- Privacy and Security
  - Trust of the user
  - Control the privacy setting
- Interaction with the camera network

#7: Applications

What applications can (only) be solved by DSC

- Demonstrations
  - Large scale networks eg., for surveillance
  - Small scale networks eg., for entertainment, home environments
  - Only single camera application?
- Market opportunities
- Killer Application

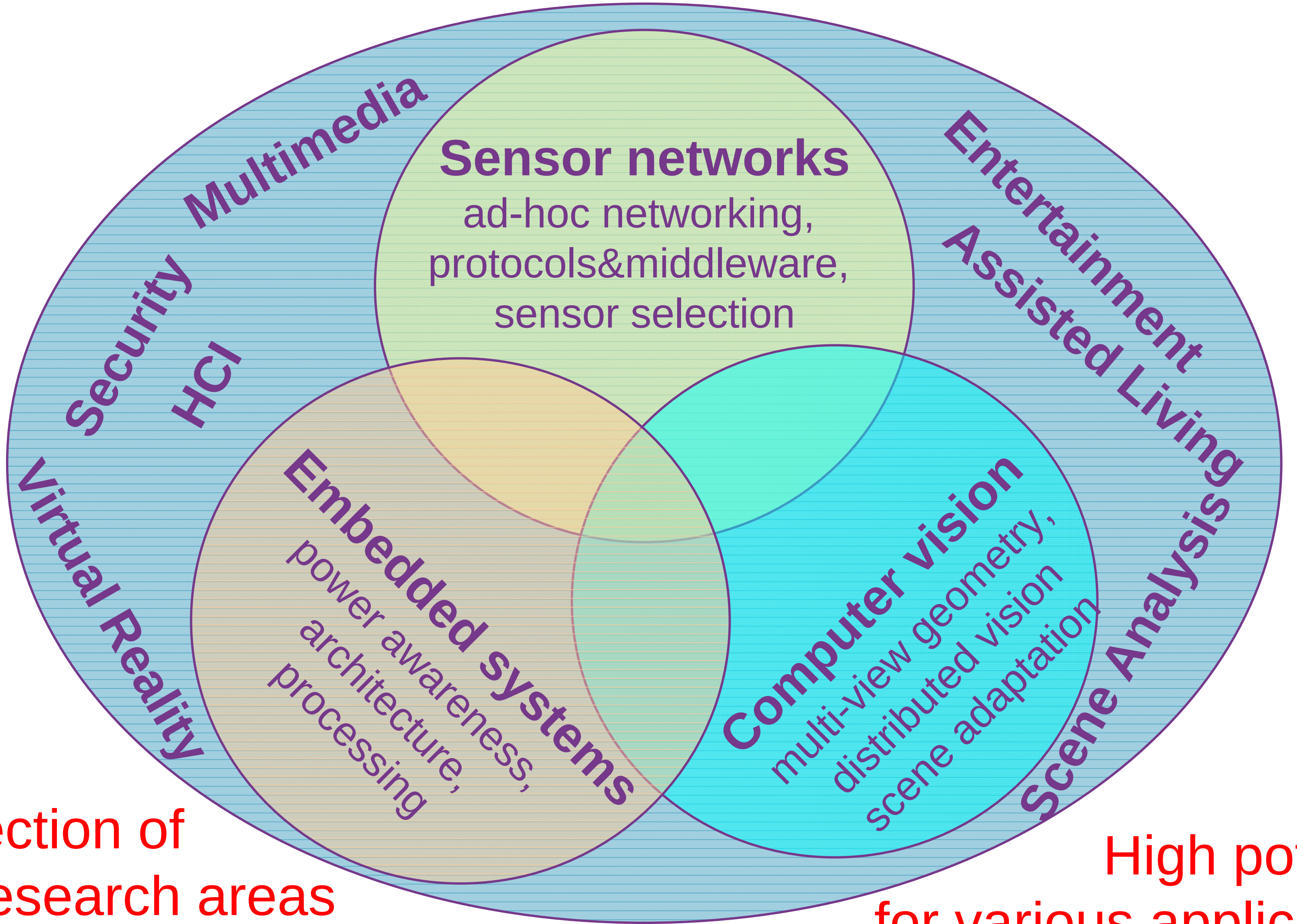
Smart Cameras

- combine
  - sensing,
  - processing and
  - communication

  in a single embedded device

- perform image and video analysis in real-time closely located at the sensor and transfer only the results
- collaborate with other cameras in the network (multi-camera system)

DSC is Interdisciplinary Research



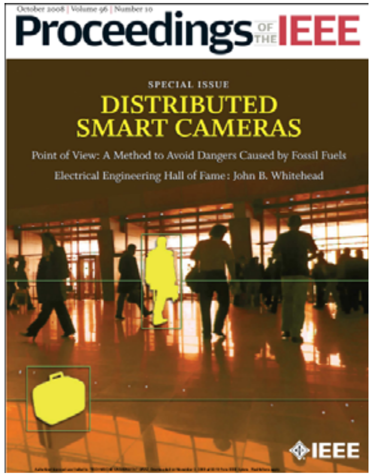
Intersection of
“hot” research areas

High potential
for various applications

Further Information

Web site: http://pervasive.uni-klu.ac.at

To probe further:



www.icdsc.org

www.icephd.org