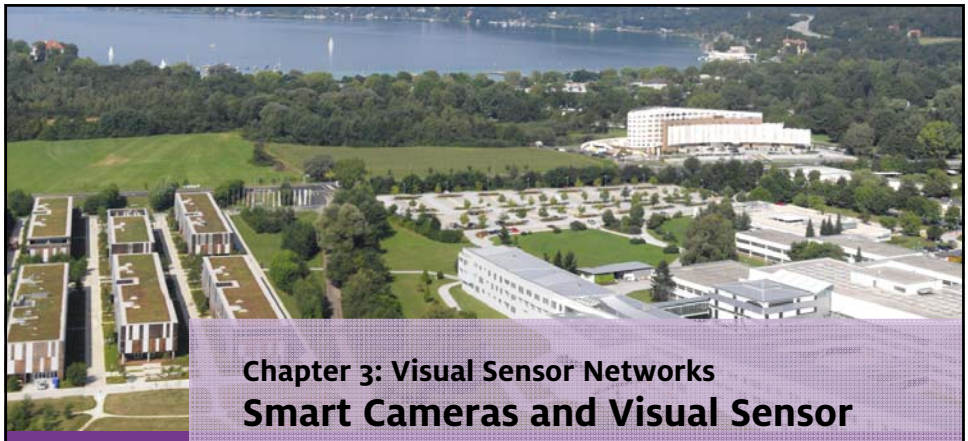


Chapter 3: Visual Sensor Networks

Smart Cameras and Visual Sensor Networks

ALPEN-ADRIA UNIVERSITÄT
KLAGENFURT | WIEN | GRAZ
FAKULTÄT FÜR TECHNISCHE WISSENSCHAFTEN
Institut für Vernetzte und Eingebettete Systeme

Bernhard Rinner

Agenda

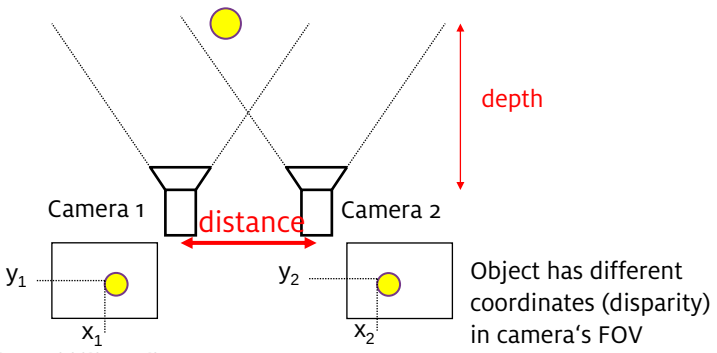
Chapter 3: Visual Sensor Networks

- Advantages & Challenges of Distributed Cameras
- Characteristics of Visual Sensor Networks
- Research Directions

Advantages and Challenges of Distributed Cameras

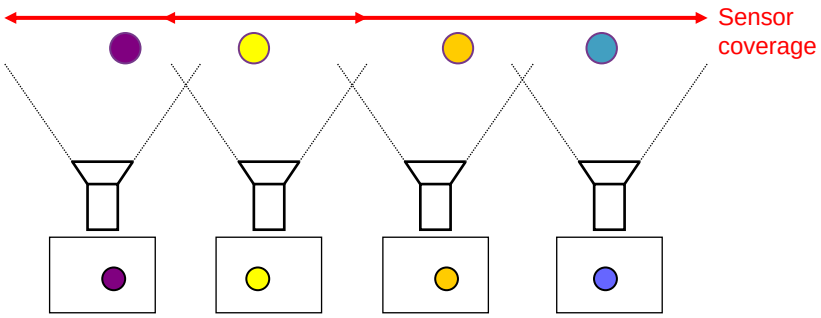
Advantage: 3D Information

- When we know the camera geometry
  - compute depth information based on different perspectives
  - stereo camera setup



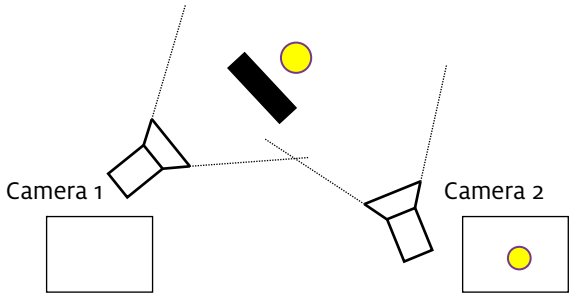
Advantage: Enlarged Field of View

- Enlarge the sensor coverage
  - setup with overlapping or non-overlapping field of views (FOVs)
  - at „constant“ resolution



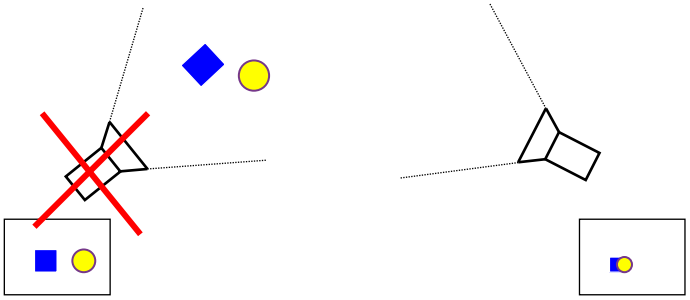
Advantage: Resolve Occlusions

- Alternate FOV may help to resolve occlusions
  - often in dynamic environments with moving objects



Advantage: Redundancy

- If a camera breaks down we may get useful information from another camera, typically with
  - different FOV
  - different resolution



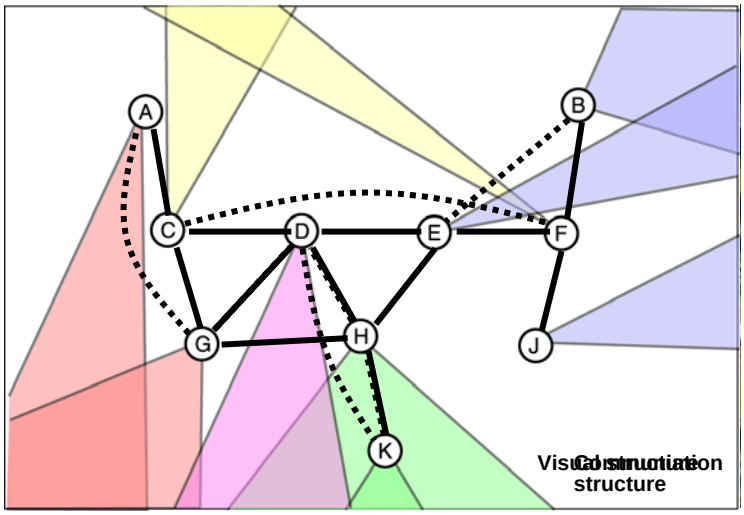
Challenge: Amount of Data

- A camera network produces a huge amount of data which has to be
  - transferred
  - stored
  - analyzed, processed, and „observed“, respectively
- Example: Subway in London with 40.000 cameras
  - single camera „generates“ approx. 260 Mbit/s (uncompressed)
  - requires extremely powerful network, storage and server!
- Video compression does not really help
  - compression rates in the range of 10 – 100
  - loss of image quality and large computational effort at camera

Challenge: Energy and Data Distribution

- Each camera requires energy and delivers data. Setting up the infrastructure for energy & data distribution is
  - tedious
  - expensive
  - and limits the applicability of multi-camera networks
- Reducing energy consumption and data transfer
  - battery-powered, energy harvesting
  - local processing, reduced bandwidth in wireless networks
- Dependency between energy consumption and data transfer
  - transferring data (over wireless channel) more expensive than processing it

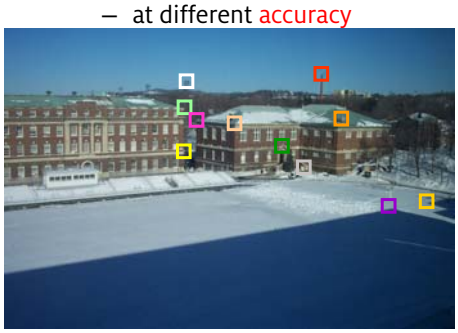
Challenge: Structure

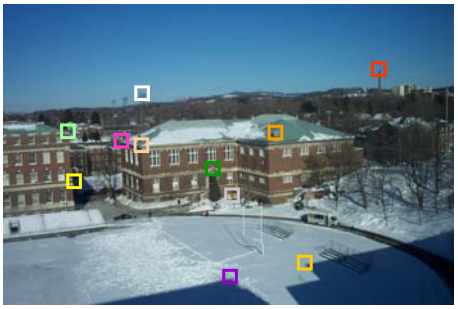


Challenge: Spatial & Temporal Calibration

- Images of (overlapping) cameras must be „calibrated“ in space and time
  - complex procedure – only required during initialization (stationary cameras)
  - at different accuracy

[Radke 2007]

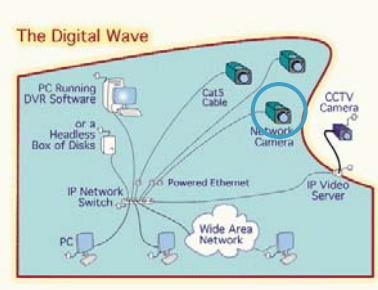




Characteristics of Visual Sensor Networks

Video Surveillance Network

- 1st and 2nd generation
  - primarily analog frontends
  - backend systems are digital
- 3rd generation
  - all-digital systems
- 3+ generation
  - smart cameras
  - surveillance tasks run on-site on smart cameras, e.g.,
    - video compression
    - accident detection
    - stationary vehicles (tunnels)
    - traffic statistics
    - wrong-way drivers
    - vehicle tracking



[Regazzoni, Ramesh, Foresti. Special Issue on Video Communications, Processing and Understanding for Third Generation Surveillance Systems. Proceedings of the IEEE. October 2001]

Video Surveillance Network (2)

- Even third generation networks rely on “heavy” infrastructure.
  - Camera nodes: sensor, onboard processing (encryption)
  - Network: hierarchically structured, wired, large bandwidth
  - Energy: dedicated supply
- Surveillance networks typically consist of large number of cameras
- Processing in network is fixed; (compressed) data is streamed to control centre

Characteristics of VSN

- Visual sensor networks lie somewhere in between wireless sensor networks (WSN) and multi-camera/surveillance networks.
- VSN have unique characteristics (wrt. traditional WSN)
- Resource limitations
  - Need to process and transfer large amounts of data
  - Energy and bandwidth
- On-board processing (cp. Smart cameras)
  - Challenging vision algorithms
  - Adaptive behavior

[Soro et al. A Survey of Visual Sensor Networks. Advances in Multimedia 2009]

Characteristics of VSN (2)

- Real-time operation
  - Most applications require real-time analysis (camera to user)
- Location and orientation information (spatial calibration)
  - Absolute or relative coordinates and orientations
  - (Multi-)camera calibration
- Time Synchronization (temporal calibration)
- Data Storage
  - Access to historic data necessary, eg., frame buffer, detected events
  - Stored data may be discarded over time
- Autonomous Camera Collaboration
  - cp. Distributed smart cameras (DSCs)

[Soro et al. A Survey of Visual Sensor Networks. Advances in Multimedia 2009]

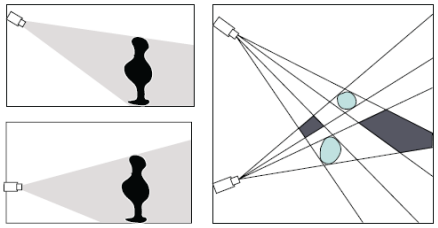
(Potential) Advantages of DSC

- 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
- …

Research Directions of Visual Sensor Networks

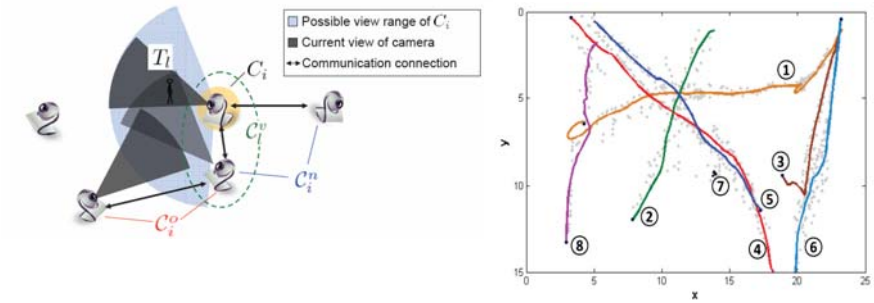
Signal Processing Algorithms

- Camera calibration
  - Identify camera's intrinsic and extrinsic parameters
  - Complete /pixel-accurate calibration is expensive
  - Alternative: autonomously detect „neighboring" cameras
- (Multi-view) Object detection
  - Resource-aware algorithms
  - Example: Occupancy reasoning (occupancy maps vs. certainty maps)



Signal Processing Algorithms (2)

- (Multi-view) object localization and tracking
  - Example: distributed consensus algorithms



[Song et al. Tracking and Activity Recognition Through Consensus in Distributed Camera Networks. IEEE Trans. on Image Processing, 2010]

Communication Protocols

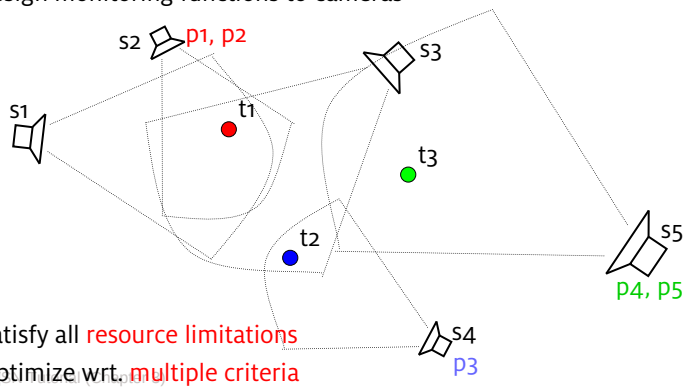
- VSN experience different communication patterns
  - Delivery of events
  - Streaming (raw/compressed) data
  - Exchanging control messages
- Various approaches
  - Energy efficient communication, e.g., MAC protocols
  - Reliability
  - Delay-sensitive protocols
  - Collaborative image data routing

Sensor Management

- Manage the available VSN resources autonomously (“self-*”)
  - Number of camera nodes
  - Communication channels/bandwidth
  - Processing power
  - Energy lifetime
- Various management objectives
  - Sensor placement/coverage
  - Best view selection
  - Power reduction (dynamic power management)

Example: VSN Configuration

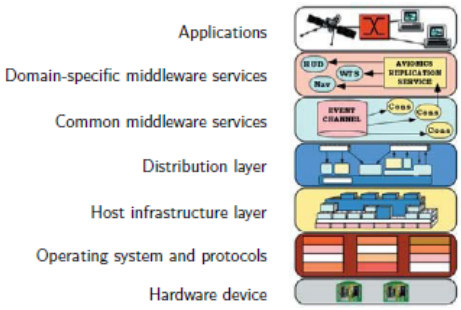
- Resource-aware configuring a VSN
  - Select a set of cameras to monitor an area of interest
  - Set the sensor (frame rate, resolution, PTZ) to achieve QoS
  - Assign monitoring functions to cameras



  - Satisfy all resource limitations
  - Optimize wrt. multiple criteria

Camera and Network Architecture

- Single camera
  - Check chapter 2
- Networks/Testbeds
- Middleware systems



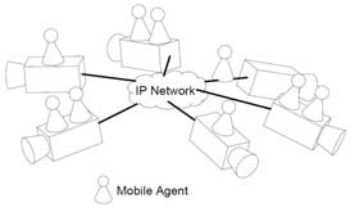
[Schmidt. Middleware for Real-Time and Embedded Systems. Comm ACM 2002.]

[Rinner et al. Embedded Middleware for Smart Camera Networks and Sensor Fusion. In Multi-Camera Networks: Principles and Applications, 2009]

[Akyildiz et al. Wireless Multimedia Sensor Networks: Applications and Testbeds. PIEEE 96(10), 2008]

System-level Software

- How to design the software at node and network level
  - Middleware system supporting the special requirements in VSN, eg.
    networking and data/event distribution
    in-network data storage
    special services (calibration, neighborhood detection etc)
- Example: Agent-based middleware



[Rinner et al. Embedded Middleware for Smart Camera Networks and Sensor Fusion. In Multi-Camera Networks: Principles and Applications, 2009]

Summary

- VSNs exploit various advantages of distributed camera sensors such as increased coverage, redundancy and 3D information.
- Distributed cameras impose various challenges such as huge amount of data, required infrastructure and (network) topology.
- VSN have unique characteristics (wireless sensor networks vs. surveillance camera networks)
- Current research addresses signal processing, communications, architecture and middleware issues.

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