A short History of Smart Cameras

A personal perspective

ALPEN-ADRIA UNIVERSITÄT
KLAGENFURT | WIEN GRAZ

FAKULTÄT FÜR TECHNISCHE WISSENSCHAFTEN

Institut für Vernetzte und Eingebettete Systeme

Bernhard Rinner
http:/bernhardrinner.com

Prologue

My research on smart cameras has started at Graz University of Technology more than 10 years ago when we explored various computing platforms for embedded vision algorithms.

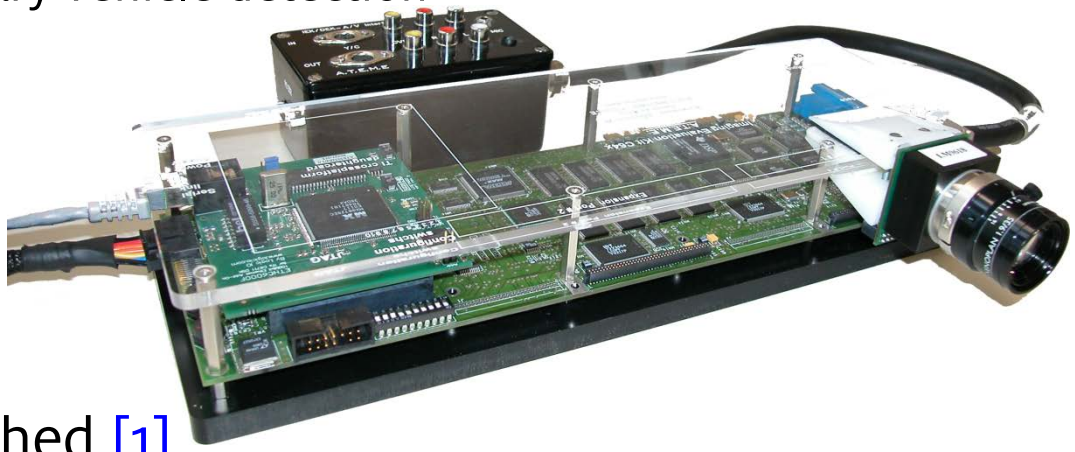
We took advantage of the confluence of three key ingredients

- a motivated graduate student,
- a visionary research paper, and
- a sustainable cooperation

and initiated an exciting and successful research endeavor at two universities resulting in 8 PhD graduations, more than 60 papers and the acquisition of more than 2 M€ external funding.

The early days

- Our first prototype was based on a Network Video Development Kit (NVDK) from Ateme. It provided
  - TMS320DM64x DSP (Texas Instruments)
  - LM-9618 CMOS sensor(National Semiconductor)
  - Onboard stationary vehicle detection

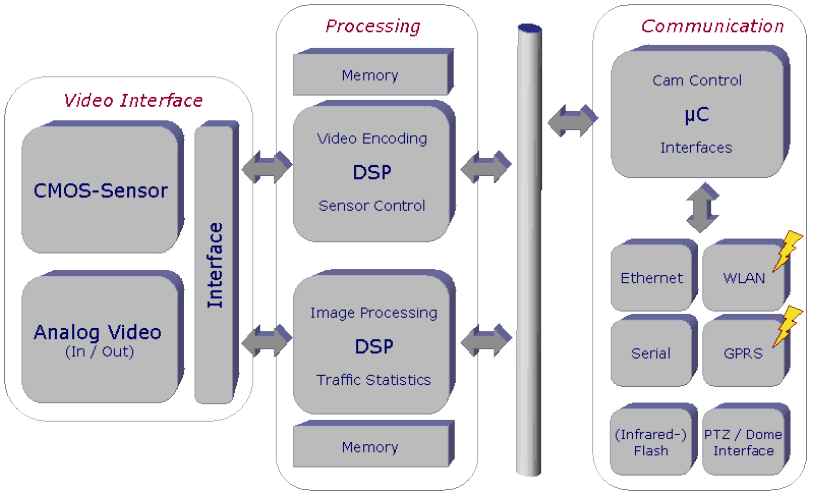


- First paper published [1]

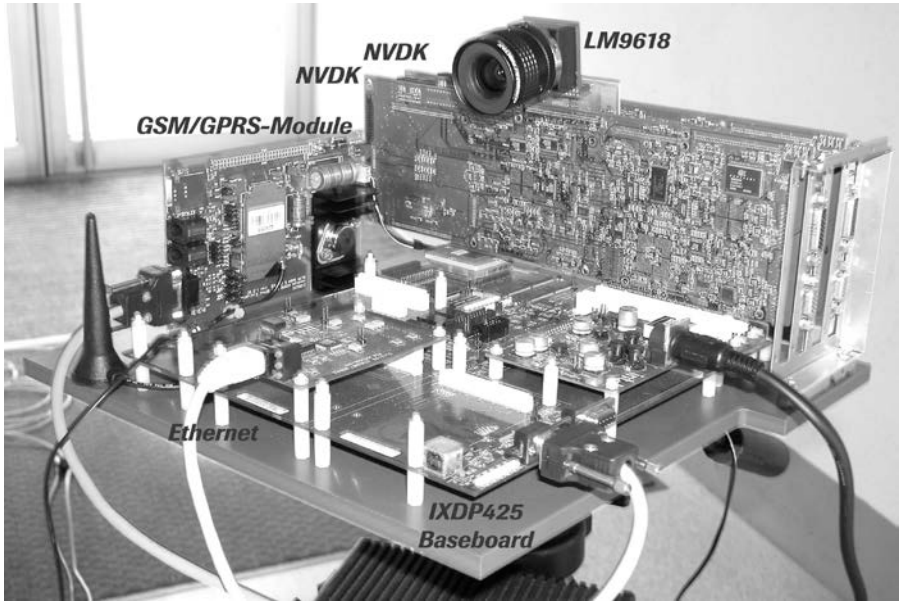
  Bramberger, Pflugfelder, Maier, Rinner, Strobl and Schwabach. A Smart Camera for Traffic Surveillance. In Proc. WISES 2003

Improved performance

- Scalable SmartCam architecture with dedicated DSP units for high computing performance

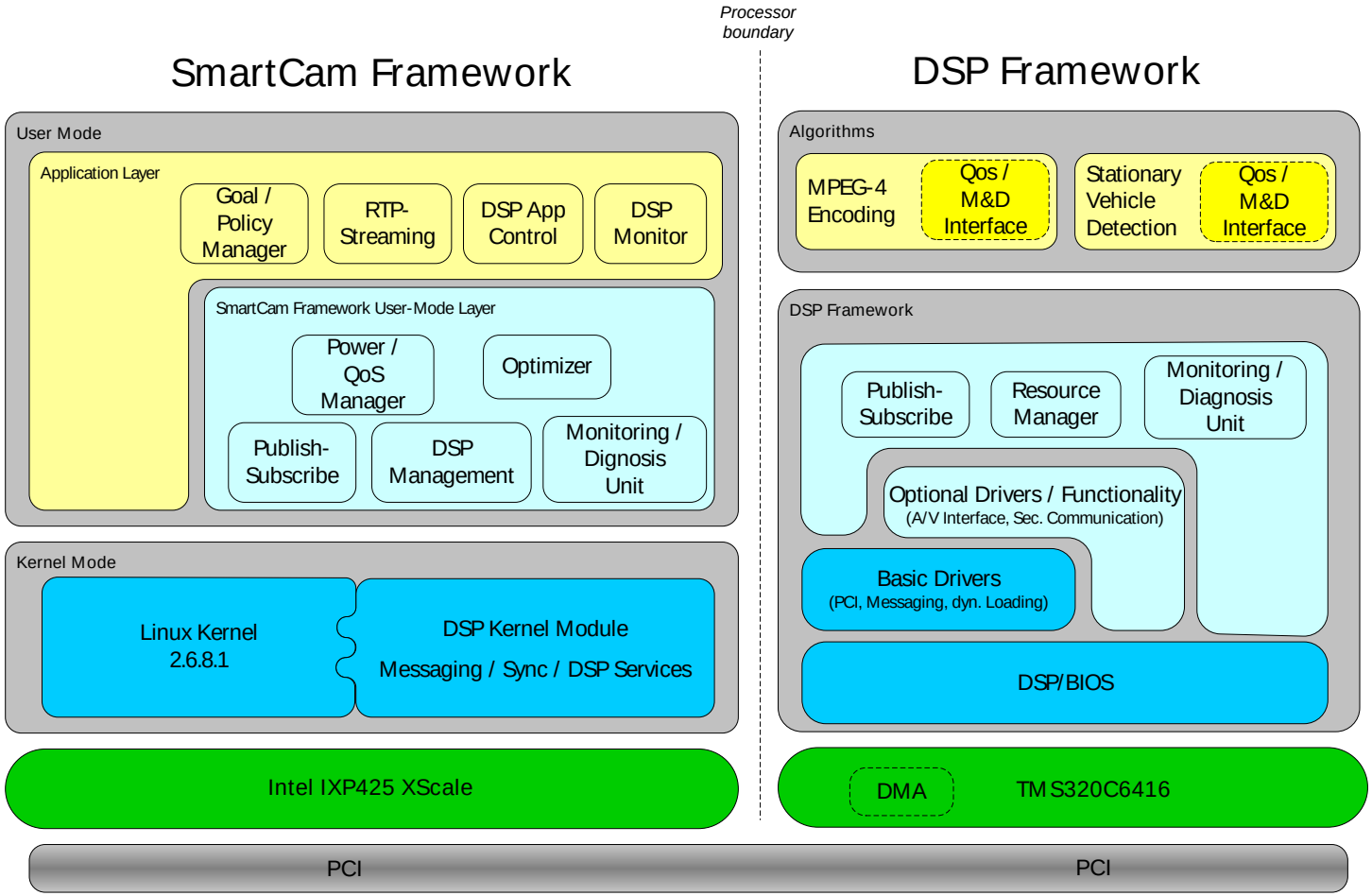


- Multi-DSP prototype [2,3]
  - Intel-based baseboard
  - NVDKs as DSP system
  - 3 variations
    (different host processors)
    XScale PXA, XScale IXP, P4M



SmartCam Software Framework

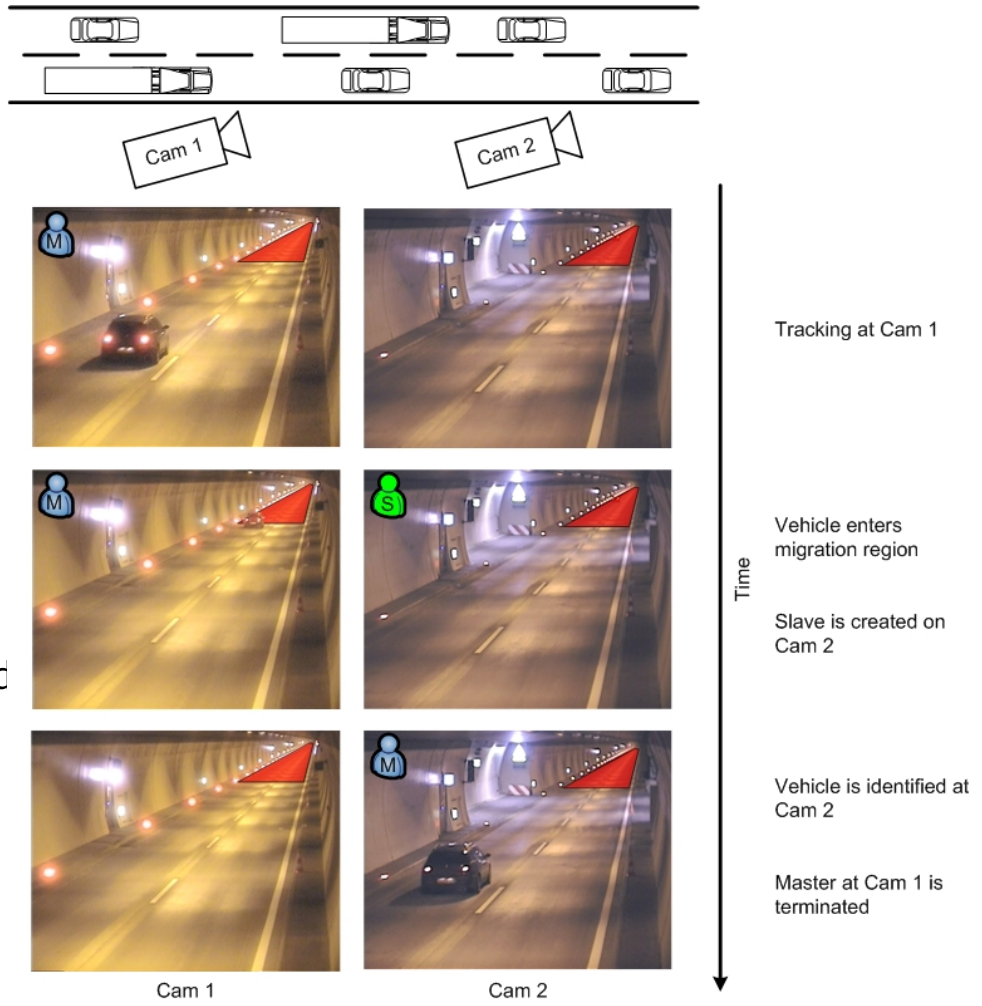
- Publish-subscribe data transfer between DSPs and host [11]



Networks of Smart Cameras

- Mobile Agent System
  as middleware system for smart camera networks [5,6]

- Autonomous multi-camera tracking as case study [4]



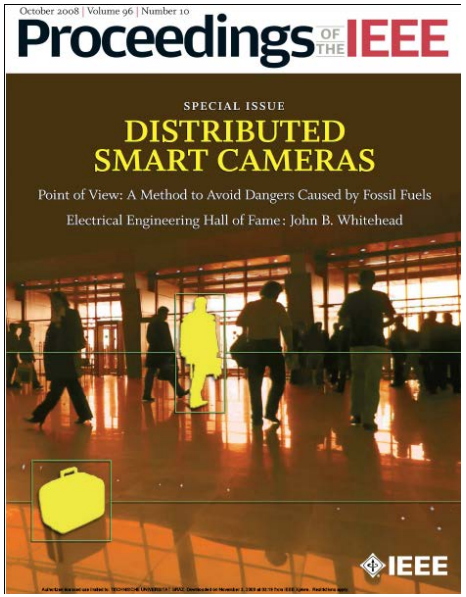
Bramberger, Doblander, Maier, Rinner, and Schwabach. Distributed Embedded Smart Cameras for Surveillance Applications. Computer. 39(2) 2006

First Graduates

- Michael Bramberger. Distributed Dynamic Task Allocation in Clusters of Embedded Smart Cameras. PhD thesis. 2005
- Arnold Maier. Dynamic Power-Aware Camera Configuration in Distributed Embedded Surveillance Cameras. PhD thesis. 2006
- Andreas Doblander. A Novel Software Framework for Multi-Processor Embedded Smart Cameras. PhD thesis. 2006

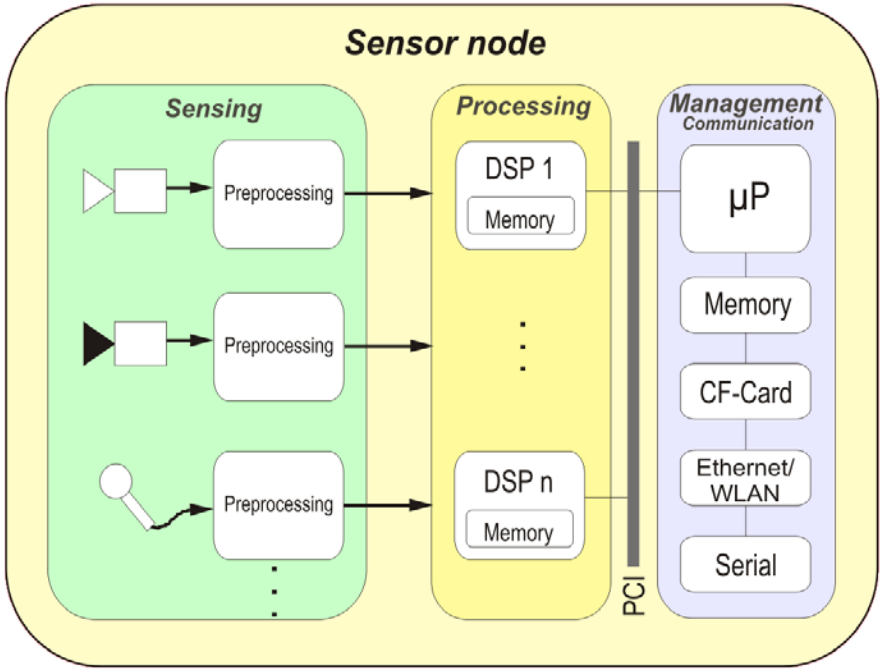
Community Building

- Organization of SenSys workshop on Distributed Smart Cameras. Oct 2006 (with W. Wolf)
- Initiation of an ACM/IEEE Conference. 1st edition 2007 in Vienna (with H. Aghajan, R. Kleihorst and W. Wolf)
- Editing a special issue in Proc. of the IEEE. Oct 2008 [9] (with W. Wolf)



Towards Multi-Sensor Networks

- Augment individual cameras with multiple sensors and perform sensor fusion at multiple levels [8]
- Transform SmartCams to high-performance sensor nodes
- Apply multi-sensor node to traffic monitoring



Next Wave of Graduates

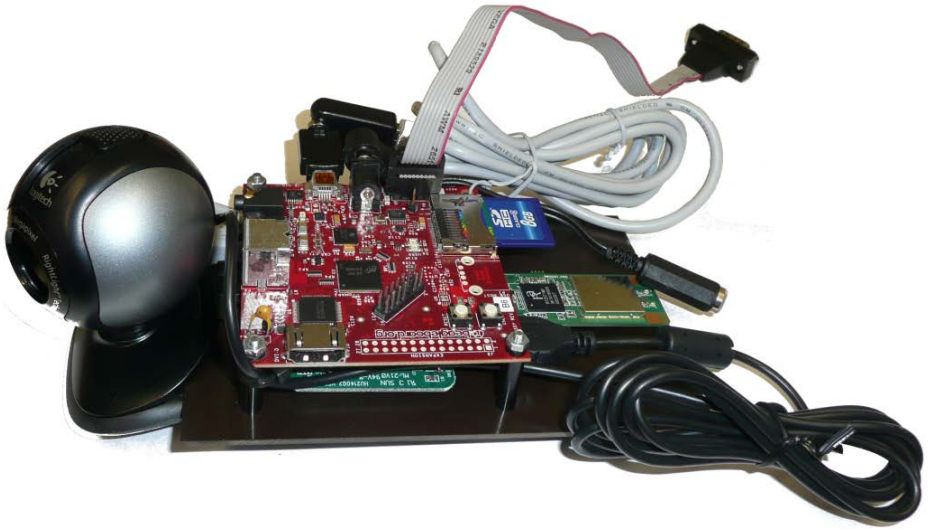
- Andreas Klausner. Multi-Sensor Multi-Level Information Fusion on Embedded Systems. PhD thesis. 2008
- Markus Quaritsch. A Lightweight Agent-Oriented Middleware for Distributed Smart Cameras. PhD thesis. 2008
- Allan Tengg. A Generic, Dynamically Reconfigurable Data Fusion Architecture based on Distributed Embedded Systems. PhD thesis. 2008

A new Place

I moved to Klagenfurt University in March 2007 where I was fortunate to continue research with a highly motivated team – partly composed of members from my old place.

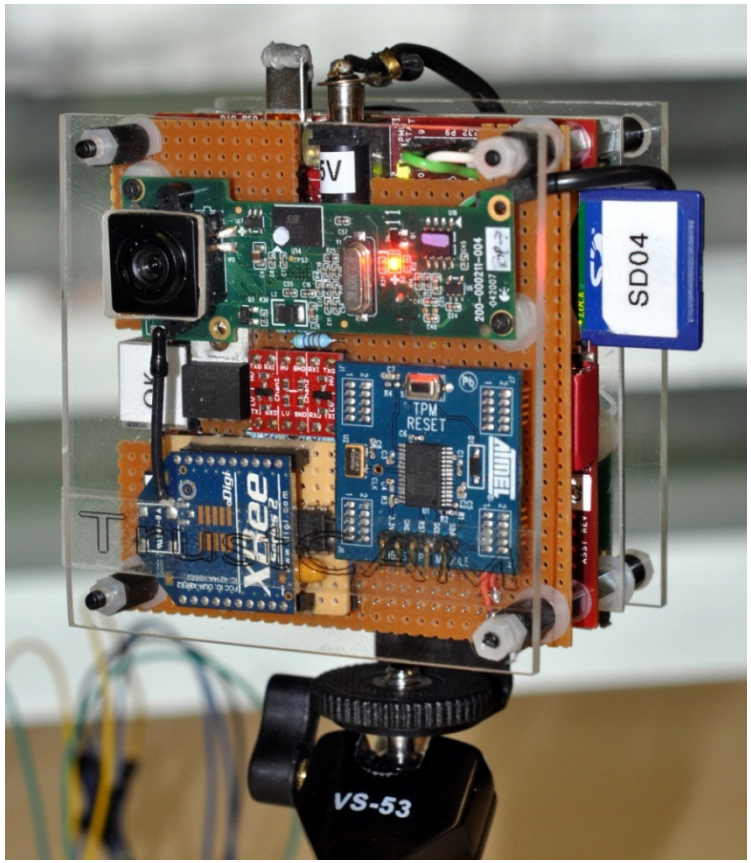
Pervasive Smart Camera

- A node prototype for visual sensor networks [7,10]
- Key features
  - Beagle Boards as main board with USB connected peripherals
  - TI OMAP3530 processor: ARM Cortex A8 @ 600MHz, TI C64x DSP @430MHz
  - 128MB RAM, 256MB Flash
  - SD-Card, USB, DVI, audio-in/out
- Dual radio interface
  - 802.11g (RA-2571)
  - 802.15.4 (CC2420)



Secure and Privacy-aware SmartCam

- TrustCAM [12,15] combines
  - authenticity, integrity and timestamping for outgoing data
  - confidentiality and privacy protection
  - platform status monitoring and reporting
- HW-based security with TPM
  - TI OMAP 3530 CPU (ARM & DSP)
  - 256 MB RAM
  - VGA color image sensor
  - wireless: 802.11b/g WiFi and 802.15.4 (XBee)
  - Atmel hardware TPM on I2C bus



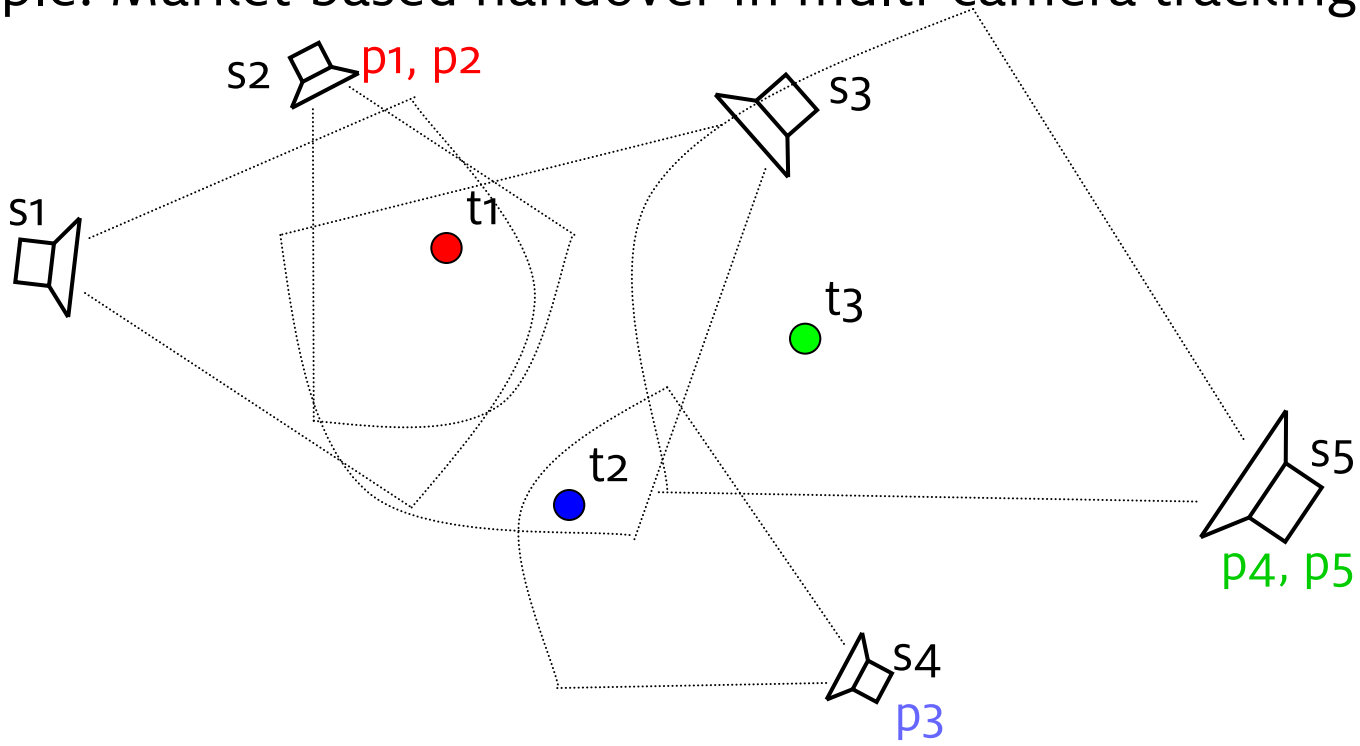
First Graduates at Klagenfurt

- Andreas Starzacher. Multi-Sensor Real-Time Data Fusion on Embedded Computing Platforms. PhD thesis. 2010

- Thomas Winkler. Security and Privacy in Smart Camera Networks. PhD thesis. 2011

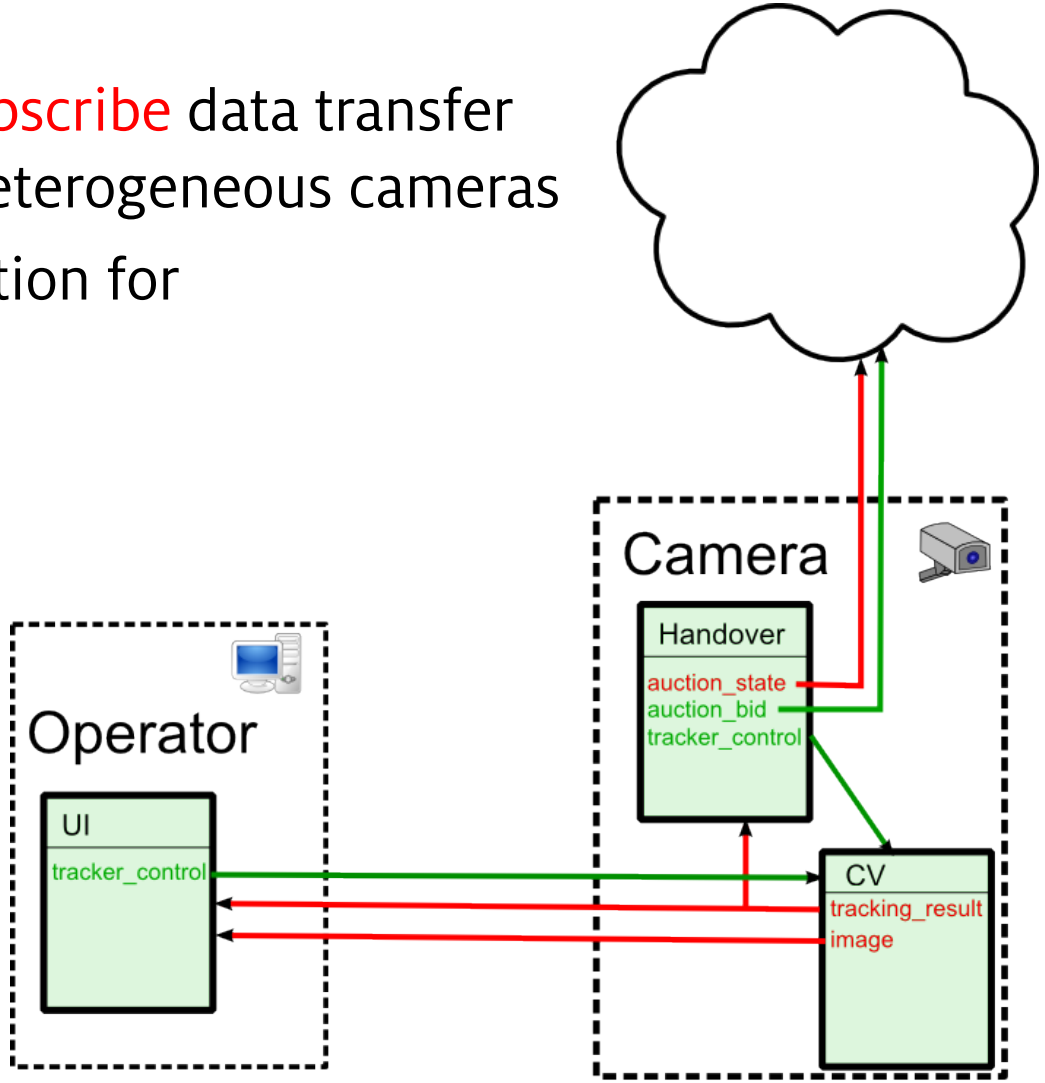
Camera Network Configuration

- A configuration describes what is processed where in the network [13,14]
  - Centralized, distributed or self-aware approaches
- Example: Market-based handover in multi-camera tracking [17]



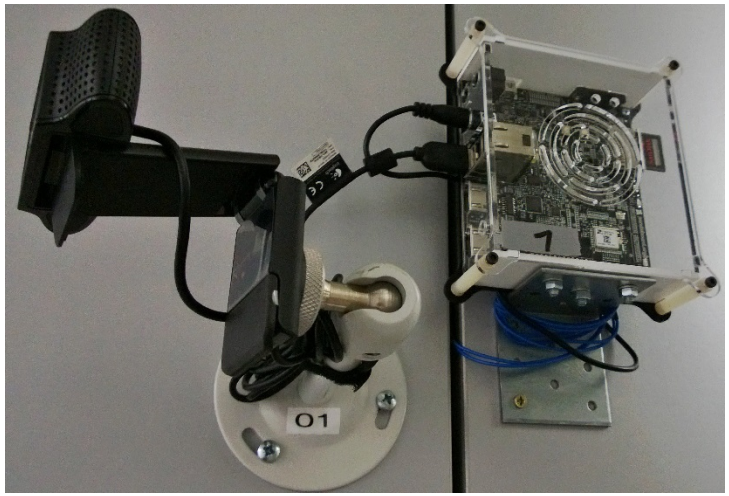
Middleware for Camera Networks

- Distributed publish-subscribe data transfer among a network of heterogeneous cameras
- Prototype implementation for Multi-Camera Tracking



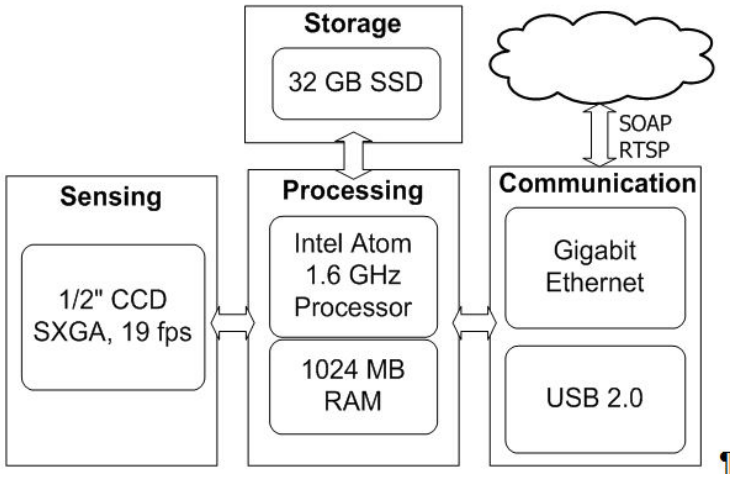
Prototyping Camera Platform

- Flexible high-performance platform running Linux
  - PandaBoard-es as main board with USB / CSI / GPMC connected components
  - TI OMAP 4460 processor, 2x ARM Cortex A9 @ 1.2 GHz, 2x Cortex M3
  - 1GB DDR2 SDRAM
  - SD-Card, USB, DVI, HDMI, audio
  - 802.11 b/g/n
  - Bluetooth 2.1 + Bluetooth 4 Low Energy
  - Ubuntu 12.04 Linux
- Camera modules
  - USB
  - Camera Serial Interface (CSI)
  - External module connected via GPMC using FPGA



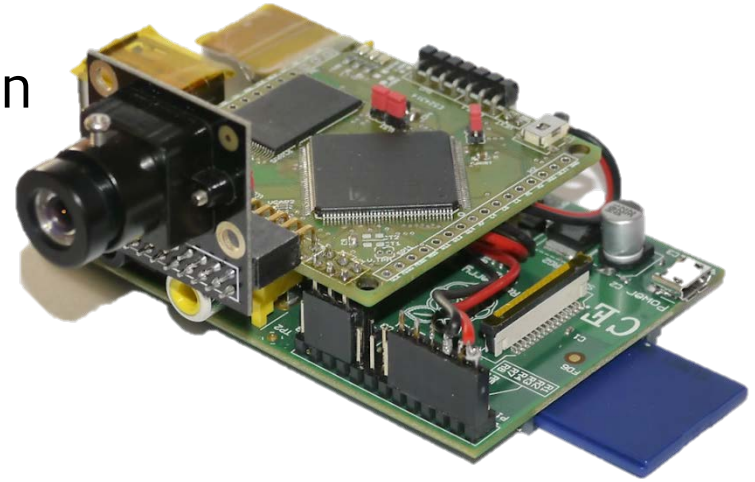
Smart Camera for Traffic Monitoring

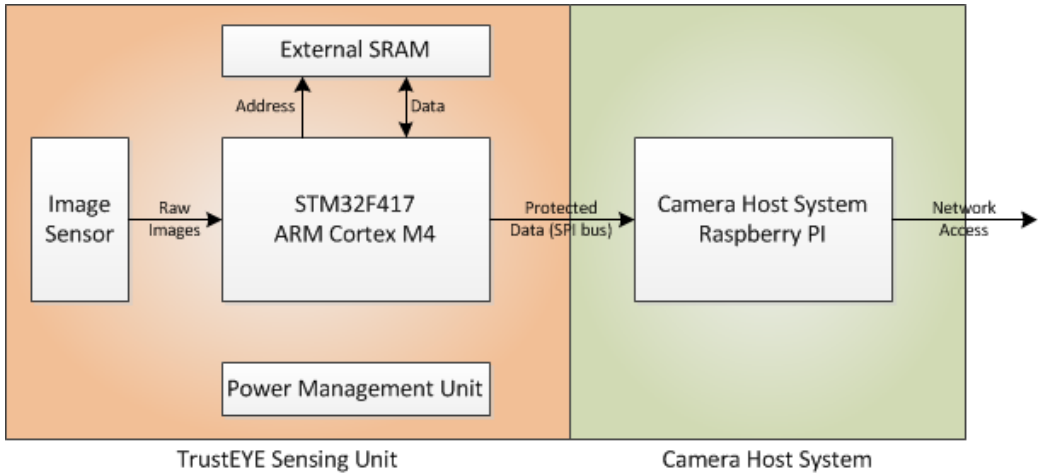
- Perform image and video analysis in real-time onboard [16]
  - Compute traffic density and speed
  - Stream short video on demand
- Use Atom-based and commercially available platform



Trustworthy Camera Sensor

- Putting security and privacy protection closer to sensor [18]
- TrustEYE sensing unit prototype
  - ARM Cortex M4 (168MHz, 192kB SRAM, 1MB Flash, SIMD and DSP extensions)
  - SRAM (4MB)
  - Image sensor (OV5642)
  - Security chip
- Raspberry Pi as host system via SPI bus



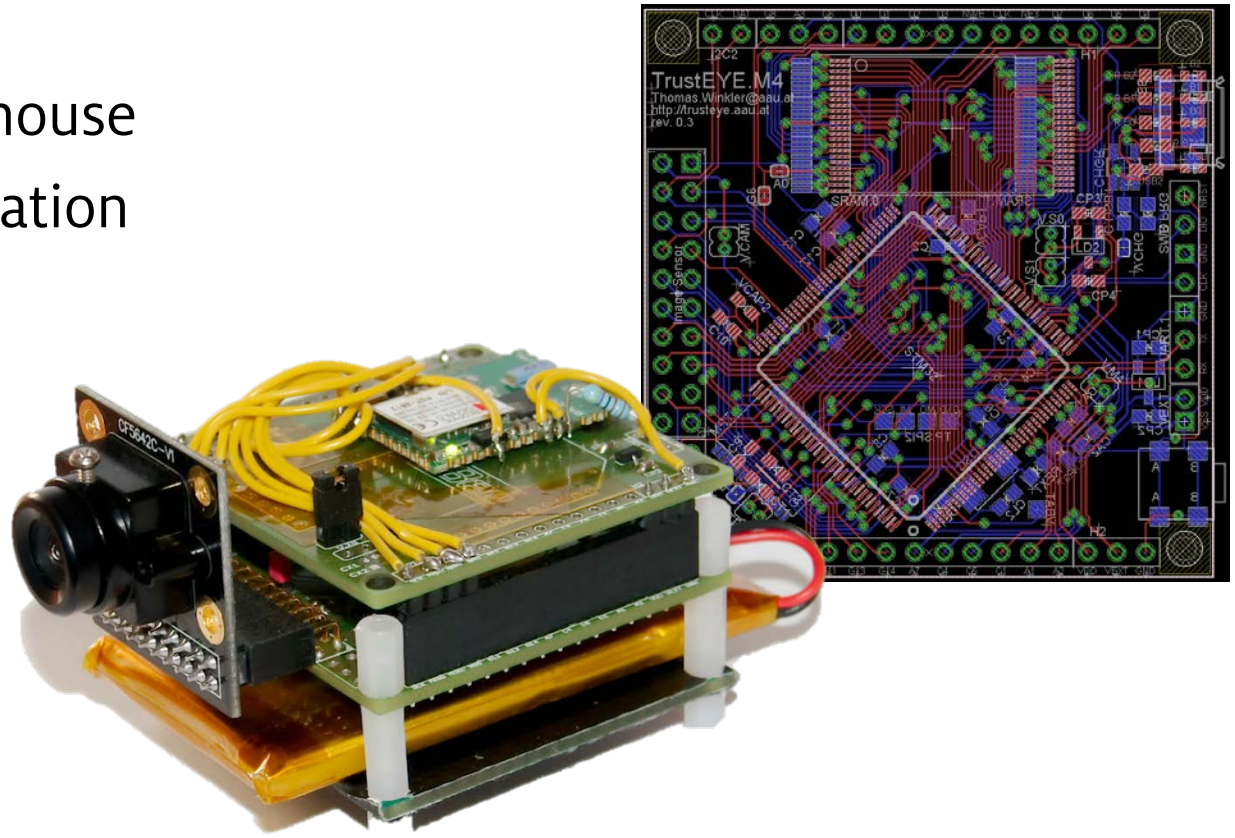


TrustEYE Prototype

- STM32F417 has HW accelerators for AES256 and SHA256
- Supports implementation of secure boot (firmware protection)

- PCB designed in-house
- Driver implementation
- KEIL RTX RTOS

- Standalone use
- WiFi extension module



Epilogue

Over the last decade we have witnessed remarkable improvements in this field of research and have been able to contribute some achievements, including

- successful demonstration of various prototypes,
- fostering community building, and
- initiating commercial exploitation.

However, when you look back you realize that there are many more open problems now than you initially imagined.

Acknowledgements

Michael Bramberger, Bernhard Dieber, Andreas Doblander, Lukas Esterle, Herwig Guggi, Milan Jovanovic, Umair Khan, Andreas Klausner, Arnold Maier, Felix Pletzer, Markus Quaritsch, Melanie Schranz, Wolfgang Schriebl, Andreas Starzacher, Allan Tengg, Thomas Winkler

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[13] Micheloni, Rinner and Foresti. Video Analysis in PTZ Camera Networks - From master-slave to cooperative smart cameras. IEEE Signal Processing Magazine, 27(5), pages 78-90, 2010.

[14] Dieber, Micheloni and Rinner. Resource-Aware Coverage and Task Assignment in Visual Sensor Networks. IEEE Transactions on Circuits and Systems for Video Technology, 21(10):1424 - 1437, Oct. 2011.

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