VCA
Video Coding & Architectures research group

Advanced embedded/FPGA video processing in UHD Imaging for surveillance

Prof.dr.ir. Peter H.N. de With,

With contriibutions from
E. Janssen, S. Geerts (Ampleye, Prodrive)
B. Beers, C. Barreto (CycloMedia)

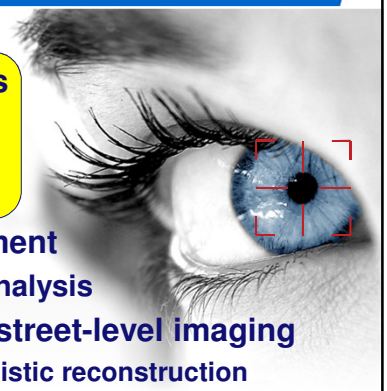
PRODRIVE TECHNOLOGIES
cyclomedia Smart Imagery Solutions
TU/e Technische Universiteit Eindhoven University of Technology
Where innovation starts

EE- VCA / Video Coding & Architectures

- Faculty Electrical Engineering (EE)
  - Dept. Signal Processing Systems (SPS)
  - Video is a rich area (computing, bandwidth)
    - Healthcare, Geo-ref. Imaging,
    - Security and Surveillance, Automotive, et
- Video Coding and Architectures
  - Research group of 25-30 researchers: three assistant professors and 2/3 PhDs
  - Also implementations
    - real-time architectures, fast coding & analysis systems, special embedded
  - Extensive industrial cooperations
    - Philips Research & Healthcare, Siqura/TKH
    - Prodrive, CycloMedia, ViNotion, Bosch, etc.

VCA

Presentation overview



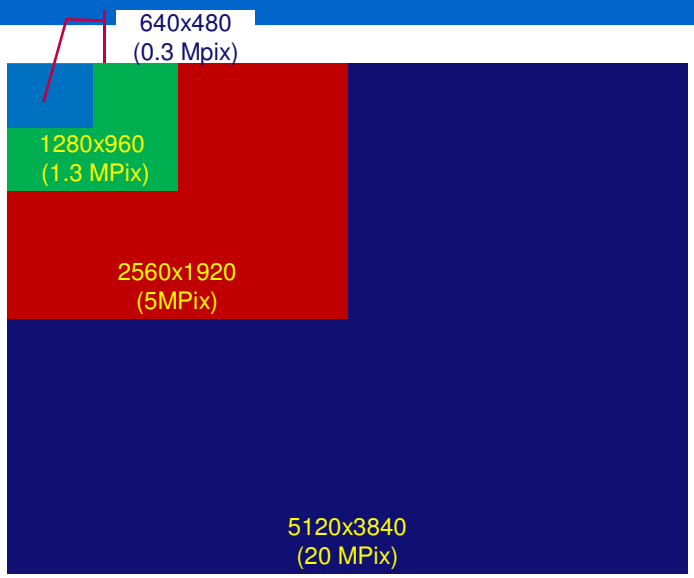
- Short intro UHD Camera Systems
  - CMOS sensor camera outline
  - Quality enhancement issues
  - Architecture and programming
- Case 1: Local contrast enhancement
  - Improve details for surveillance analysis
- Case 2: Moving camera for UHD street-level imaging
  - Environment modeling and photorealistic reconstruction
- Conclusions

Camera specification outline / New sensor

ampleye
See everything

- Camera specificat's summary
- Sensor: CMOS 35 mm
- High resolution 20 Mpixels
- Coding: JPEG2000 still + H.264 @ 1280x960 video 30 fps
- Throughput:
  - 6 fps 20 MP parallel with H.264
  - 30 fps 4 MP parallel with H.264
  - 155 Mpixels/s
- Integrated 16-field Motion Det.
- Lens: Canon EF
- Interface: ONVIF

Resolution: Video image size comparison



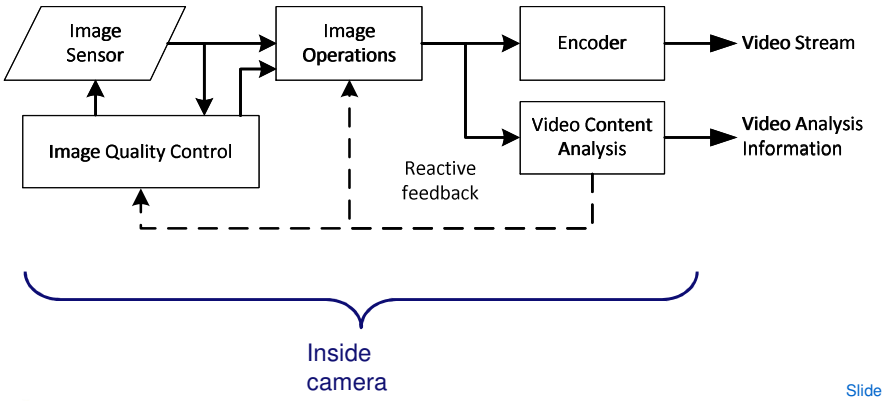
Slide 4

New sensor needs new enhancement…

- Sensor needs tuning of Pict. Quality, involving functions:
- Debayering/demosaicing
- Equalization of sensor segments
- Noise reduction functions
- White balancing
- Contrast enhancement
- ……
- Also: JPEG-2000 compression

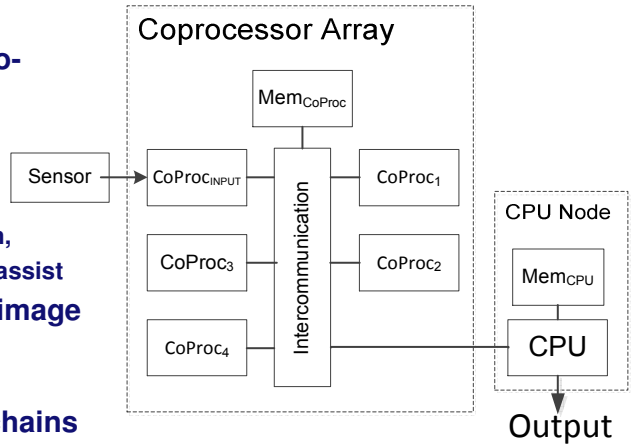
Slide 5

Camera system concept (e.g. Ampleye)

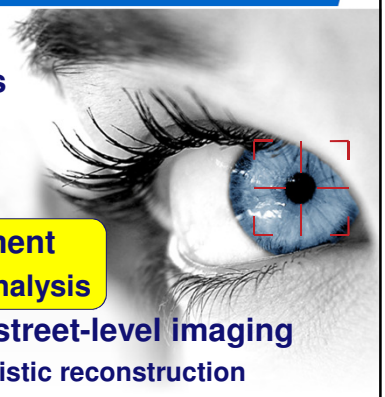


Proposed embedded architecture:
Flexible heterogeneous co-processor

- **Maximum bandwidth: 19.2 Gbps**
- **Task-specific co-processors**
  - **Sensor comm.,**
  - **de-mosaicing,**
  - **compression,**
  - **motion detection,**
  - **communication assist**
- **Programmable image pipeline paths**
- **DSP functions programm. as chains**
  - **HW/SW co-design**



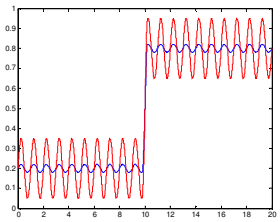
Presentation overview

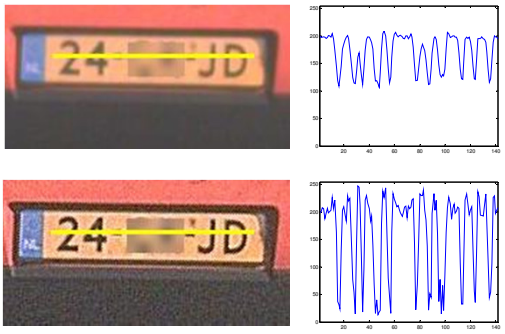


- **Short intro UHD Camera Systems**
  - **CMOS sensor camera outline**
  - **Quality enhancement issues**
  - **Architecture and programming**
- **Case 1: Local contrast enhancement**
  - **Improve details for surveillance analysis**
- **Case 2: Moving camera for UHD street-level imaging**
  - **Environment modeling and photorealistic reconstruction**
- **Conclusions**

Local contrast enhancement / Problem

- Improve visibility in all regions (be global)
- Enhance local details (and yet local)





Slide 10

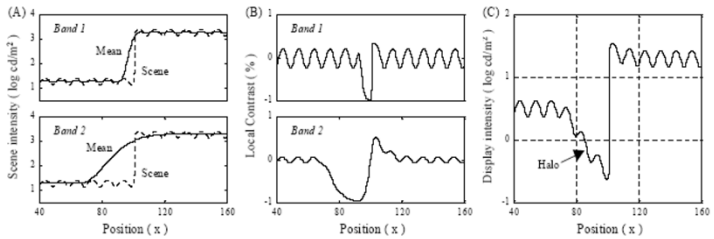
Local contrast enhancement / Literature

Overview of functions

Algorithm	Formula	Reference
Contrast Preserving Gamma (CPG)	$y_{GAIN} = (F * x)^{\frac{1}{\gamma}}$ $y = x \cdot y_{GAIN}$	[8]
Single Scale Retinex (SSR)	$y = m^{\{\log_m x - \log_m (F * x)\}}$	[9]
Multi Scale Retinex (MSR)	$y = m^{\{\log_m x - \sum_{n=1}^{N} w_n \log_m (F_n * I)\}}$	[10]
Locally Adaptive Contrast Enhancement (LACE)	$y = x + \sum_{n=1}^{N} G_n \cdot ([F_{n-1} - F_n] * x)$, with $G_n = {}^{C_n}/_{LD_n{}^2}$	[8]

Slide 11

Local contrast enhancement / ‘Halos’

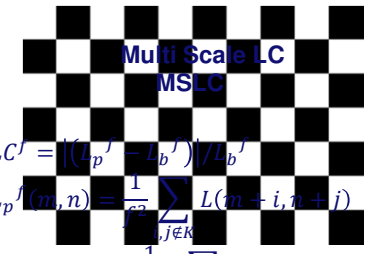


Input | Halos | No halos

Normal filters | Edge-preserving filters

Slide 12

Local contrast enhanc. / objective metric

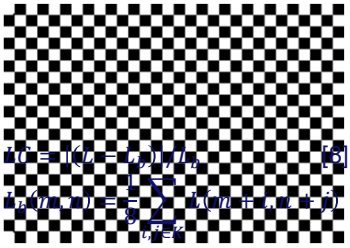


Multi Scale LC
MSLC

$$LC^f = |(L_p^f - L_b^f)|/L_b^f$$

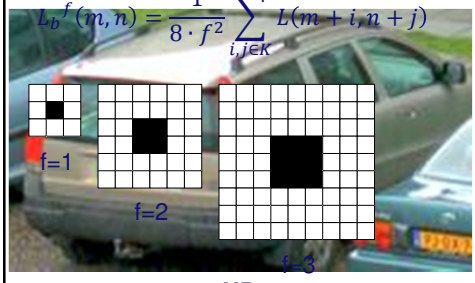
$$L_p^f(m,n) = \frac{1}{f^2}\sum_{i,j\in K} L(m+i,n+j)$$

$$L_b^f(m,n) = \frac{1}{8\cdot f^2}\sum_{i,j\notin K} L(m+i,n+j)$$

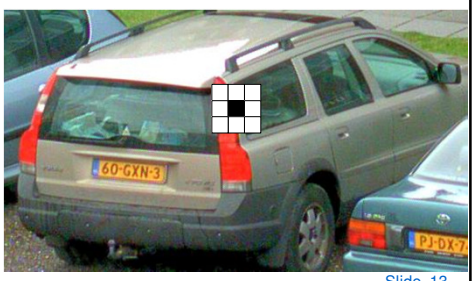


$$LC = |(L_p - L_b)|/L_b \quad [3]$$

$$L_p(m,n) = \frac{1}{9}\sum_{i,j=-1}^{1} L(m+i,n+j)$$



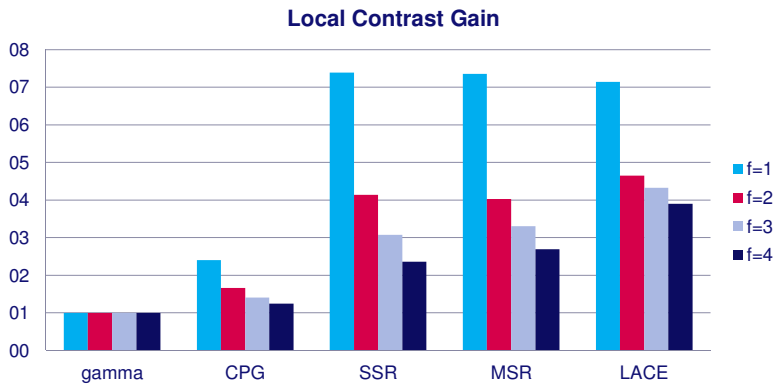
HD



UHD

Slide 13

Local contrast enhanc. / objective metric

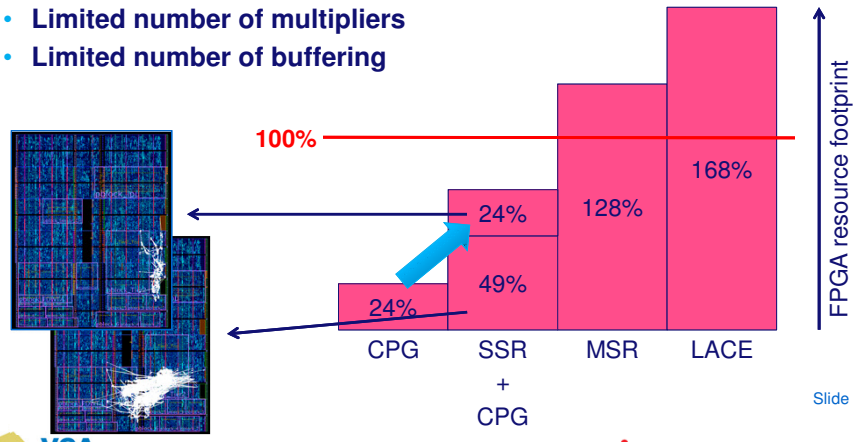


Slide 14

Local contrast enh. / complexity metric

Implementation Complexity in FPGA

- Limited number of adders (logic)
- Limited number of multipliers
- Limited number of buffering



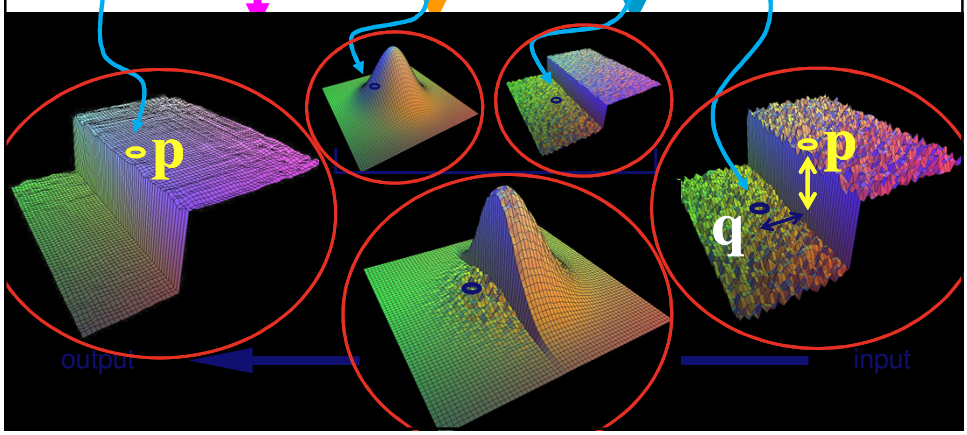
Slide 15

Local contrast enhanc. / Improvement

architecture & improvement : simplified bilateral filter

new — not new — new

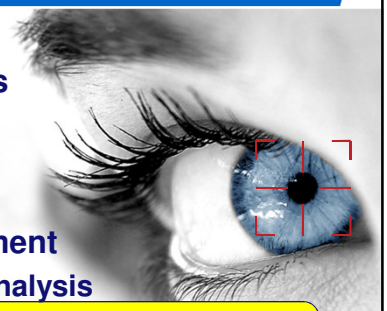
$$BF[I]_{\mathbf{p}} = \frac{1}{W_{\mathbf{p}}} \sum_{\mathbf{q}\in S} G_{\sigma_s}\left(\|\mathbf{p}-\mathbf{q}\|\right) G_{\sigma_r}\left(|I_{\mathbf{p}} - I_{\mathbf{q}}|\right) I_{\mathbf{q}}$$



Local contrast enhanc. / Conclusions

- MSLC metric for objective LC comparison of UHD images
- Combination of
  - Contrast preserving gamma
  - Single scale Retinex with bilateral filtering
- New simplified bilateral filtering (67% less complex)

Presentation overview



- Short intro UHD Camera Systems
  - CMOS sensor camera outline
  - Quality enhancement issues
  - Architecture and programming
- Case 1: Local contrast enhancement
  - Improve details for surveillance analysis
- Case 2: Moving camera for UHD street-level imaging
  - Environment modeling and photorealistic reconstruction
- Conclusions

Slide 18

VCA Video Coding & Architectures research group | Design Automation Emb Conf. 04 November 2015 / PdW | cyclomedia Smart Imagery Solutions | TU/e Technische Universiteit Eindhoven University of Technology

Recording of UHD cycloramas

- Car-mounted system
- Visual cameras
- Positioning system
- Embedded proc.

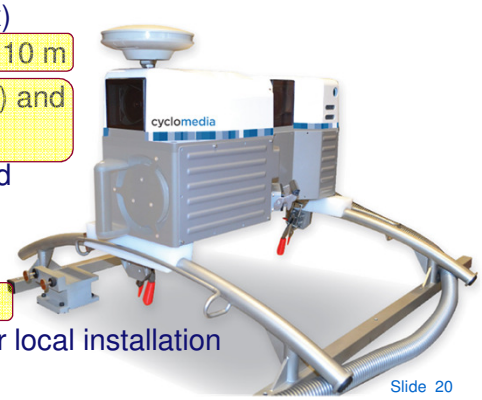
cyclomedia Smart Imagery Solutions

Slide 19

VCA Video Coding & Architectures research group | Design Automation Emb Conf. 04 November 2015 / PdW | cyclomedia Smart Imagery Solutions | TU/e Technische Universiteit Eindhoven University of Technology

Cyclorama recording system (DCR10)

- 5 cameras to fully cover surroundings
- In order to guarantee correct image geometry: 1 single virtual entrance pupil, no parallaxes
- 14,400 x 7,200 Pix (> 100 MPix)
- 0.025° per pixel → 0.44 cm @ 10 m
- Accurate geo-reference (10 cm) and orientation (0.1°)
- Up to 120 km/h recording speed at 5 m interval
- Patented
- Very efficient recording & proc.
- Delivery through web hosting or local installation



Slide 20

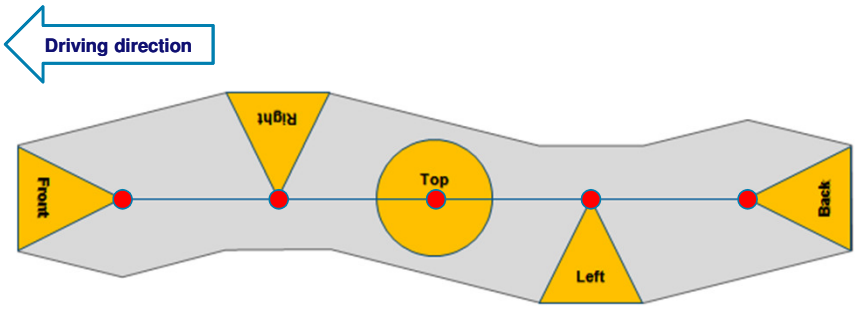
Recording of UHD cycloramas (DCR10)

Multiple HW/SW system components

Slide 21

UHD cyclorama recording principle

Multiple view image capturing



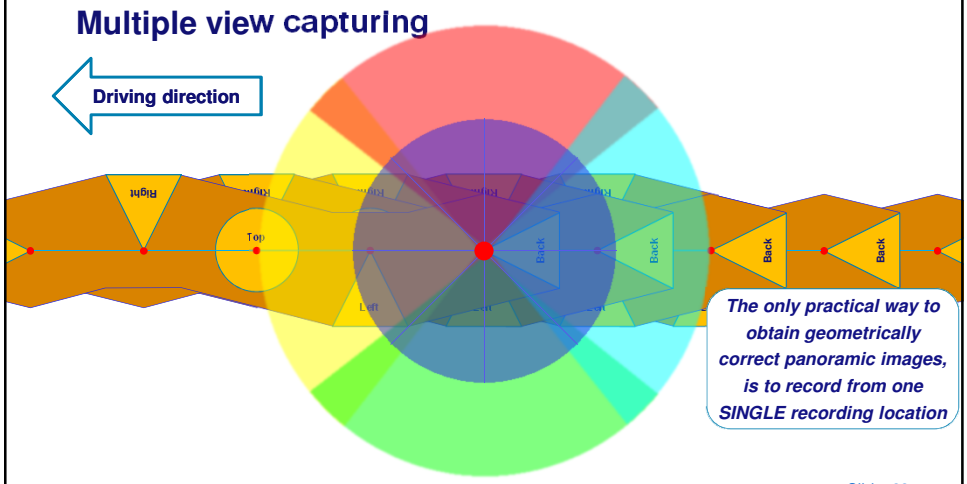
1. Front 2. Right 3. Top 4. Left 5. Back

Slide 22

VCA Video Coding & Architectures research group
Design Automation Emb Conf.
04 November 2015 / PdW
cyclomedia Smart Imagery Solutions
TU/e Technische Universiteit Eindhoven University of Technology

UHD cyclorama recording principle

Multiple view capturing

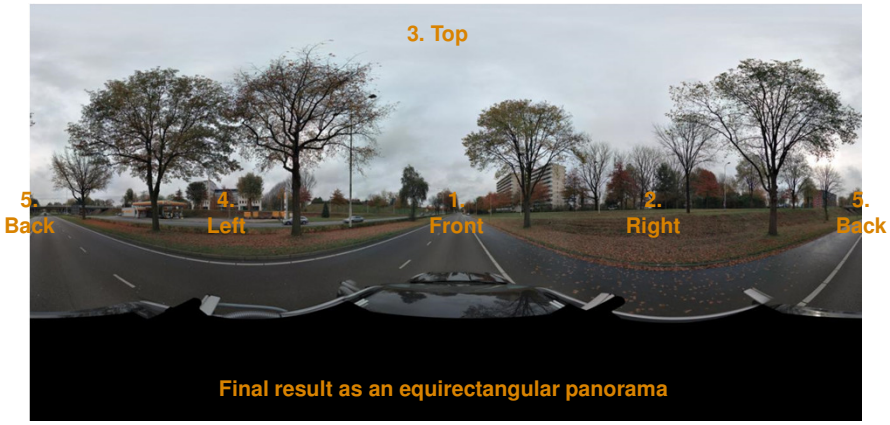


The only practical way to obtain geometrically correct panoramic images, is to record from one SINGLE recording location

Slide 23

VCA Video Coding & Architectures research group
Design Automation Emb Conf.
04 November 2015 / PdW
cyclomedia Smart Imagery Solutions
TU/e Technische Universiteit Eindhoven University of Technology

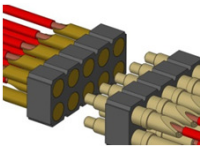
UHD cyclorama processing principle



Slide 24

Technical challenges for camera system

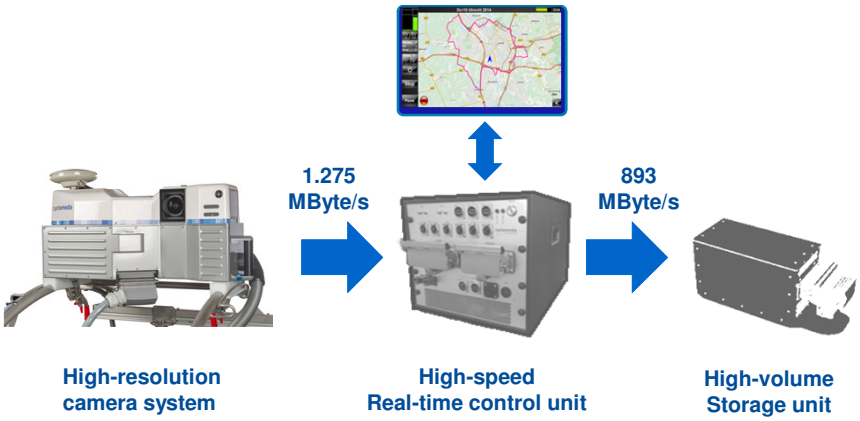
- **High scalability** (distributed components)
- **High data rates** (multi data path of 20Gbps)
- **Accurate absolute positioning** (< 10cm)
- **Accurate real time synchronization** (< 100ns)
- **Robustness to shocks and vibrations**
- **Connectivity** (100.000 mating cycles)
- **Low power budget** (< 250W)



Slide 25

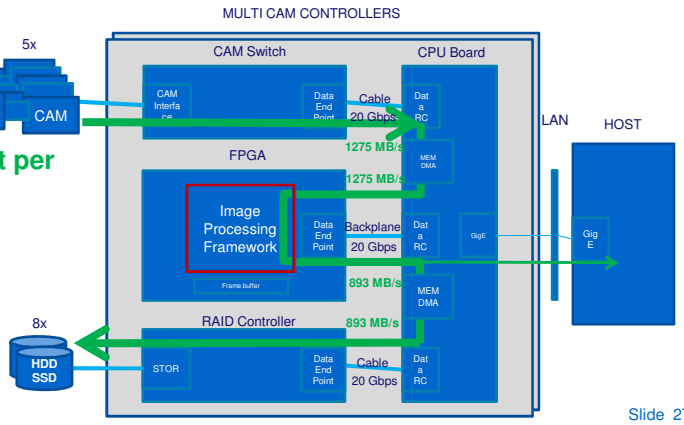
System overview of recording system

- **Multiple system components** (much more than camera)
- **Distributed image processing tasks (in/outdoor, in/out camera)**



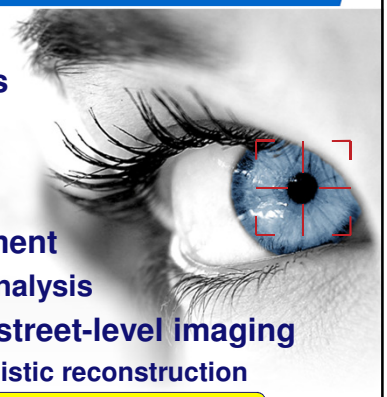
System overview of recording system

- **Multiple system components** (much more than camera)
- **Distributed image processing tasks (in/outdoor, in/out camera)**



Avg. throughput per controller
@ 10fps and
30% compression
CAMS: 1275 MByte/s
STOR: 893 MByte/s
MEM: 4336 MByte/s

Presentation overview



- Short intro UHD Camera Systems
  - CMOS sensor camera outline
  - Quality enhancement issues
  - Architecture and programming
- Case 1: Local contrast enhancement
  - Improve details for surveillance analysis
- Case 2: Moving camera for UHD street-level imaging
  - Environment modeling and photorealistic reconstruction
- Conclusions

Conclusions – (1)

- Video Analysis is also within embedded domains
  - Multimedia, Surveillance, Geo-referenced imaging, etc.
  - Current systems in the market are 1st generation
  - Higher quality is needed and more context in decision making
  - *New HQ sensors allow improved quality of detection and analysis*
- Ultra-HD Images initiate re-design proc. chain
  - Surveillance: UHD lead to very high detail imaging of object(s)
  - This implies desired improvements local areas in images
  - More detailed processing required for
    - Contrast enhancement
    - Noise reduction, Color processing, Sharpness, …
    - Compression standards

Conclusions – (2)

- **UHD imaging via multi-view reconstruction**
  - Advanced stitching processing for better panoramic image reconstruction
  - This requires high computational effort which is partly embedded close / in camera system
- **Reconsider Emb. System design of Camera System**
  - Total system overview and requirements determine islands of computing and their implementation
  - Reconfig. computing: FPGA but also programmable Co-proc.
  - UHD imaging requires careful bandwidth analysis