

High Dynamic Range Techniques in Graphics: from Acquisition to Display

Eurographics 2005 Tutorial T7

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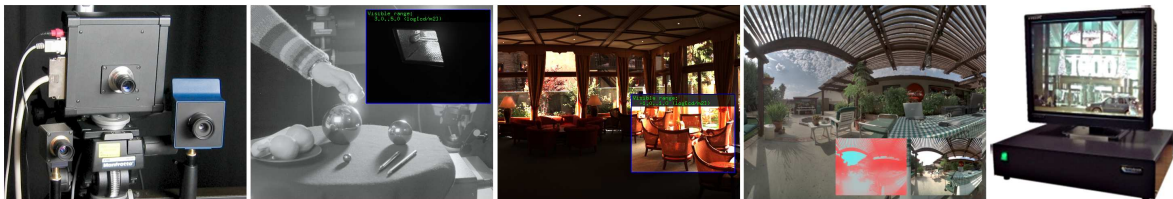
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Abstract

This course is motivated by tremendous progress in the development and accessibility of high dynamic range technology (HDR) that happened just recently, which creates many interesting opportunities and challenges in graphics. The course presents a complete pipeline for HDR image and video processing from acquisition, through compression and quality evaluation, to display. Also, successful examples of the use of HDR technology in research setups and industrial applications are provided. Whenever needed relevant background information on human perception is given which enables better understanding of the design choices behind the discussed algorithms and HDR equipment.



Description of images, from left to right:

- Acquisition of HDR data: two HDR cameras (IMS-CHIPS and LarsIII) and a high quality LDR camera Jenoptik C14.
- HDR video: a broad range of luminance values can be stored in the HDR video without loss of any perceivable details. Even the bare light bulb is faithfully registered, as visible in the blue window which scales down the luminance range.
- HDR video: a conventional video in this shot could be exposed either for the interior or exterior of the cafeteria. With the HDR video it is possible to capture and store all details of the recorded scene.
- Tone mapping: most display devices are still limited in the dynamic range of luminance and contrast that can be reproduced (right inset illustrates a naive display of an HDR image). Various tone mapping techniques allow for reduction of such a contrast. Here the image is decomposed into the areas of consistent illumination (left inset) and the contrast ratio between these areas is optimized.
- HDR display: a display system developed by the Sunnybrook company that is capable of displaying images with a dynamic range much more similar to that encountered in the real world.

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Tutorial Schedule

- Introduction - Myszkowski (10 mins)
- HDR Acquisition Techniques for Still Images and Video - Goesele and Krawczyk (35 mins)
 - Overview over HDR Acquisition Techniques
 - Multi-exposure Techniques
 - HDR Cameras and their Photometric Calibration
 - Absolute Luminance Calibration
- HDR Image Sensors for Video - Hoefflinger (20 mins)
 - CMOS Active-pixel (APS)
 - Extended Dynamic Range Sensor (XDR)
 - HDRC Imager (Very High Dynamic Range of 170 dB)
- HDR Image and Video Compression - Myszkowski (30 mins)
 - HDR Image and Video Formats
 - HDR Quality Metrics and Their Validation
 - Real-time Post-processing of HDR Video Stream (Live demo)
- Break
- HDR Displays - Heidrich and Trentacoste (35 mins)
 - Foundations: Limitations of Human Perception
 - Hardware Design
 - Processing Algorithms
- HDR Applications - Goesele, Krawczyk, and Hoefflinger (45 mins)
 - Image-based Measurements of Object and Material Properties
 - Virtual Scene Re-lighting: CAVE System for Car Interior Modeling
 - HDR Lighting in Mixed-Reality Applications
 - Application Examples in Automotive Industry and Computer Vision
- Final Remarks and Open Discussion (10 mins)

HDR Project Pages

The updated version of slides presented at Eurographics 2005 can be found under this URL:

<http://www.mpi-inf.mpg.de/resources/hdr/>

This Web page contains also links to many papers listed in the References section often along with accompanying materials. Also, source code useful for handling HDR images and video is available. Finally, HDR video samples acquired using the IMS CHIPS cameras are posted.

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Tutorial 7
High Dynamic Range Techniques in
Graphics: Acquisition to Display

**HDR Acquisition Techniques for
Still Images and Video**

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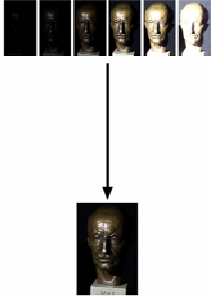
Dynamic Range of Cameras

- example: photographic camera with standard CCD sensor
 - dynamic range of sensor **1:1000**
 - exposure variation (handheld camera/non-static scene): 1/60th s – 1/6000th s exposure time 1:100
 - varying aperture f/2.0 – f/22.0 ~1:100
 - exposure bias/varying "sensitivity" 1:10
- total (sequential) 1:100,000,000
- simultaneous dynamic range still only **1:1000**
- similar situation for analog cameras

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High Dynamic Range (HDR) Imaging

- basic idea of multi-exposure techniques:
 - combine multiple images with different exposure settings
 - makes use of available sequential dynamic range
- other techniques available (e.g. HDR video)



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A Brief History of HDR Imaging

- analog film with several emulsions of different sensitivity levels by Wyckoff in the 1960s
 - Charles W. Wyckoff and Stan A. Feigenbaum. An Experimental Extended Exposure Response Film. *SPIE*, 1:117–125, 1963.
 - dynamic range of about 1:10⁸ or 160 dB

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A Brief History of HDR Imaging

- some methods assume linear response
 - Brian C. Madden. Extended Intensity Range Imaging. Technical report, University of Pennsylvania, GRASP Laboratory, 1993.
 - correct for raw CCD data
 - takes value from brightest non-saturated image

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A Brief History of HDR Imaging

- response curve first recovered by Mann and Picard
 - Steve Mann and Rosalind W. Picard. On being 'undigital' with digital cameras: Extending Dynamic Range by Combining Differently Exposed Pictures. In *IS&T's 48th Annual Conference*, pages 422–428, 1995.
 - looks only at a single pixel in several images with varying exposure times

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A Brief History of HDR Imaging

- method for digital photography by Debevec and Malik
 - Paul Debevec and Jitendra Malik. Recovering High Dynamic Range Radiance Maps from Photographs. In *Proceedings of SIGGRAPH 97*, pages 369–378, August 1997.
 - selects a small number of pixels from the images
 - performs an optimization of the response curve with a smoothness constraint

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A Brief History of HDR Imaging

- method for digital photography by Debevec and Malik
 - objective function to be minimized

$$\mathcal{O} = \sum_{i=1}^N \sum_{j=1}^P \{w(Z_{ij}) [g(Z_{ij}) - \ln E_i - \ln \Delta t_j]\}^2 + \lambda \sum_{z=Z_{min}+1}^{Z_{max}-1} [w(z)g''(z)]^2$$

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A Brief History of HDR Imaging

- method by Robertson et al.
 - Mark A. Robertson, Sean Borman, and Robert L. Stevenson. Estimation-Theoretic Approach to Dynamic Range Improvement Using Multiple Exposures. *Journal of Electronic Imaging*, vol. 12, no. 2, pages 219–228, April 2003.
 - optimization over all pixels in all images
 - more stable for noisy input data

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A Brief History of HDR Imaging

- several methods from the CAVE group
 - T. Mitsunaga and S. K. Nayar. Radiometric Self Calibration. *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition*, Fort Collins, June, 1999.
 - parametric function (nth degree polynomial) to describe response curve
 - estimates also (relative) exposure settings
 - noise removed in a preprocessing step

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A Brief History of HDR Imaging

- several methods from the CAVE group
 - objective function

$$\mathcal{E} = \sum_{q=1}^{Q-1} \sum_{p=1}^P \left[\sum_{n=0}^N c_n M_{p,q}^n - R_{q,q+1} \sum_{n=0}^N c_n M_{p,q+1}^n \right]^2$$

$$R_{q,q+1}^{(k)} = \sum_{p=1}^P \frac{\sum_{n=0}^N c_n^{(k)} M_{p,q}^n}{\sum_{n=0}^N c_n^{(k)} M_{p,q+1}^n}$$

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A Brief History of HDR Imaging

- Michael D. Grossberg and Shree K. Nayar. What can be Known about the Radiometric Response Function from Images? *Proc. of European Conference on Computer Vision (ECCV)*, Copenhagen, May 2002.
- like above but derivation from histogram
- allows for (moderate) scene movement

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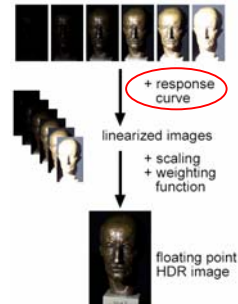
A Brief History of HDR Imaging

- other methods around in the literature
 - graphics community
 - vision community
 - imaging community
- see part on HDR sensors
- see list of references in course notes

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High Dynamic Range Imaging



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Algorithm of Robertson et al.

- Principle of this approach:
 - calculate a HDR image using the response curve
 - find a better response curve using the HDR image
- (to be iterated until convergence)
- assume initially linear response

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Algorithm of Robertson et al.

- input:
 - series of i images with exposure times t_i
 - pixel value at image position j is $y_{ij} = f(t_i x_j)$
- find irradiance x_j and response curve $I(y_{ij})$
 - $t_i x_j$ is proportional to collected charge/radiant energy
 - f maps collected charge to intensity values

$$f^{-1}(y_{ij}) = t_i x_j =: I(y_{ij})$$

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Algorithm of Robertson et al.

- additional input:
 - a weighting function $w(y_{ij})$ (bell shaped curve)
 - an initial camera response curve $I(y_{ij})$ – usually linear
- calculate HDR values x_j from images using

$$x_j = \frac{\sum_i w(y_{ij}) t_i^2 \cdot \frac{I(y_{ij})}{t_i}}{\sum_i w(y_{ij}) t_i^2} \quad x_j =$$

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Algorithm of Robertson et al.

- optimizing the response curve I :
 - start again with definition $f^{-1}(y_{ij}) = t_i x_j =: I(y_{ij})$
- minimization of objective function O

$$O = \sum_{i,j} w(y_{ij}) (I(y_{ij}) - t_i x_j)^2$$
- using Gauss-Seidel relaxation yields

$$E_m = \{(i, j) : y_{ij} = m\}$$

$$I(m) = \frac{1}{\text{Card}(E_m)} \sum_{i,j \in E_m} t_i x_j$$
- $\text{Card}(E_m)$ = number of elements in E_m

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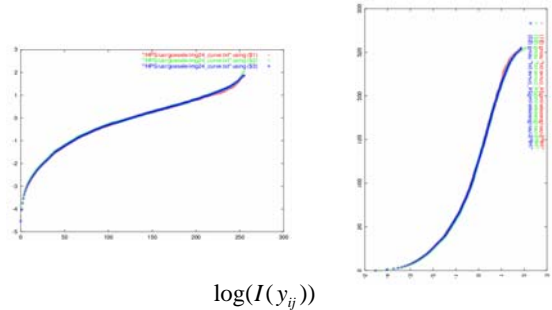
Algorithm of Robertson et al.

- both steps are iterated
 - calculation of a HDR image using I
 - optimization of I using the HDR image
 - I needs to be normalized, e.g., $I(128)=1.0$
- stop iteration after convergence
 - criterion: decrease of O below some threshold
 - usually only a couple of iterations

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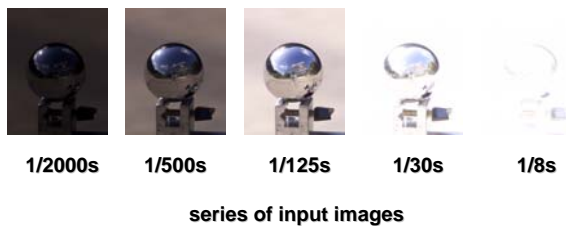
HDR Imaging: Algorithm of Robertson et al.



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HDR Example: Capturing Environment Maps



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HDR Example: Capturing Environment Maps



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Algorithm of Robertson et al.

- choice of weighting function $w(y_{ij})$ for response recovery

$$w_{ij} = \exp\left(-4 \frac{(y_{ij} - 127.5)^2}{127.5^2}\right)$$

- for 8 bit images
- possible correction at both ends (over/underexposure)
- motivated by general noise model

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Algorithm of Robertson et al.

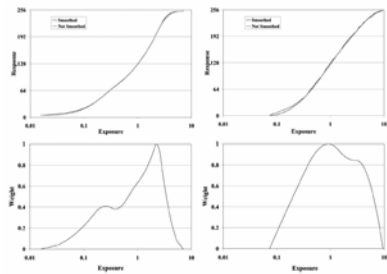
- choice of weighting function $w(y_{ij})$ for HDR reconstruction
 - introduce certainty function c as derivative of the response curve with logarithmic exposure axis
 - approximation of response function by cubic spline to compute derivative

$$w_{ij} = w(y_{ij}) = c(I_{y_{ij}})$$

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Algorithm of Robertson et al.



from Mark A. Robertson, Sean Borman, and Robert L. Stevenson. Estimation-Theoretic Approach to Dynamic Range Improvement Using Multiple Exposures. Journal of Electronic Imaging, vol. 12, no. 2, pages 219-228, April 2003.

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Input Images for Response Recovery

- my favorite:
 - grey card, out of focus, smooth illumination gradient
- advantages
 - uniform histogram of values
 - no color processing or sharpening interfering with the result

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Input Images for HDR Generation

- how many images are necessary to get good results?
 - depends on scene dynamic range and on quality requirements
 - generally a difference of two steps (factor of 4) between exposures is sufficient
 - see also:
 - M. D. Grossberg, S. K. Nayar: High Dynamic Range from Multiple Images: Which Exposures to Combine? Proc. ICCV Workshop on Color and Photometric Methods in Computer Vision, 2003.

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Algorithm of Robertson et al.

- discussion
 - method very easy
 - doesn't make assumptions about response curve shape
 - converges fast
 - takes all available input data into account
 - can be extended to >8 bit colordepth

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Handheld Acquisition of Image Series

- assumption: static scene, only translation of camera
 - Ward, Greg, "Fast, robust image registration for compositing high dynamic range photographs from handheld exposures," Journal of Graphics Tools, 8(2):17-30, 2003.
- general problems
 - stable registration between images with different exposure
 - response curve not necessarily known
 - fast algorithm

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Handheld Acquisition of Image Series

- median threshold bitmap (MTB)
- definition:
 - determine median 8-bit image value from low-resolution histogram
 - create a bi-level bitmap with
 - 0 where image value \leq median
 - 1 where image value $>$ median

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Handheld Acquisition of Image Series

edge bitmap

MTB bitmap

from Ward, Greg, "Fast, robust image registration for compositing high dynamic range photographs from hand-held exposures," Journal of Graphics Tools, 8(2):17-30, 2003.

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Handheld Acquisition of Image Series

- threshold noise
 - values right at the median threshold are not reliable
 - removed using a mask

from Ward, Greg, "Fast, robust image registration for compositing high dynamic range photographs from hand-held exposures," Journal of Graphics Tools, 8(2):17-30, 2003.

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Handheld Acquisition of Image Series

- fast registration
 - use image pyramid
 - depth determined by maximum displacement

depth = $\log_2(\text{max_displacement})$

- requires only 9 comparisons per level
- 1 bit MTB allows fast XOR operation for comparison

from Ward, Greg, "Fast, robust image registration for compositing high dynamic range photographs from hand-held exposures," Journal of Graphics Tools, 8(2):17-30, 2003.

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HDR for Dynamic Scenes

- capture at multiple time steps and compensate for movements in scene/camera position
 - Sing Bing Kang, Matthew Uyttendaele, Simon Winder, Richard Szeliski: High dynamic range video. ACM Transactions on Graphics (Proc. ACM SIGGRAPH 2003), Volume 22 (3), pages: 319 – 325, 2003.
 - solution of a vision problem

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HDR for Dynamic Scenes

- capture extended dynamic range in a single acquisition step
 - generally some kind of hardware solution
 - Manoj Aggarwal, Narendra Ahuja: Split Aperture Imaging for High Dynamic Range. International Conf. on Computer Vision, Vol. 2, pp. 10-17, 2001
 - beam from lens is split into several components and imaged by multiple sensors
 - relative exposure determined by geometry of split system

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HDR for Dynamic Scenes

- use of specialized sensor chips
 - CCD sensor is inherently a linear device
 - dynamic range limited by noise, capacity, ...

to A/D converter

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HDR for Dynamic Scenes



- use of specialized sensor chips
 - S. K. Nayar, T. Mitsunaga : High Dynamic Range Imaging: Spatially Varying Pixel Exposures. Proc. of IEEE Conf. on Computer Vision and Pattern Recognition, 2000.
 - add neutral density filters on top of individual sensels
 - similar to Bayer pattern for color capture

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HDR for Dynamic Scenes



- use of specialized sensor chips
 - multiple technologies to implement multi-exposure techniques in hardware
 - sensels with logarithmic instead of linear response (i.e., perform logarithm in analog domain)
 - see part on HDR image sensors for video
 - images are usually processed and quantized by camera software
 - photometric calibration?

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High Dynamic Range Techniques in
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**HDR Cameras and their
Photometric Calibration**

Grzegorz Krawczyk
MPI Informatik

Why do we need calibration?

- Obtain meaningful data from cameras
- Have common data in heterogeneous camera systems
- Use the camera as a measurement tool



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Overview

- Two approaches to calibration
- Choice of appropriate calibration target
- Camera response recovery
- Example calibration of 2 cameras
- Accuracy of HDR sensor vs. multi-exposure techniques

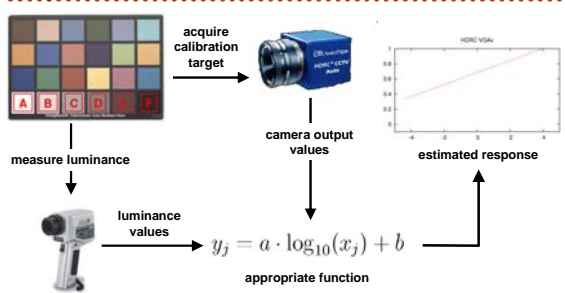
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Two Approaches to Calibration

1. Fit an *a priori* response to measurements
 - Requires measurement tools (luminance meter, color checker board)
 - Varied, controlled lightning conditions are preferable (known light sources, dark room)
2. Recover the camera response curve
 - Multiple exposures of arbitrary scene
 - Requires high contrast scene

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1. Response Function Fit



measure luminance → luminance values → $y_j = a \cdot \log_{10}(x_j) + b$ → appropriate function

acquire calibration target → camera output values → estimated response

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Limitations of Function Fit Approach

- High confidence only in the sampled data
- Difficult to verify that the assumption on the response curve is correct
- Multiple illumination conditions required to calibrate the response in high dynamic range

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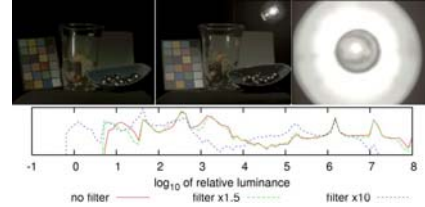
2. Camera Response Recovery

- Use LDR multi-exposure techniques to recover the full shape of the response curve
- Need appropriate calibration target
- Pitfalls of various methods
 - Assumption on continuous response
 - Polynomial approximation of the response
 - Very high computational complexity for >8bits
- Appropriate method: [Robertson et. al 2003]

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Calibration Target



- Scene with very wide dynamic range
- ND filters to simulate different exposures

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Example Calibration



- Silicon Vision LarsIII camera
 - Locally auto-adaptive sensor (16bit)
 - Individual integration time for each pixel
 - Information per pixel:
 - Collected signal
 - Integration time
 - A type of multi-exposure sensor

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Example Calibration



- Silicon Vision LarsIII camera
 - Locally auto-adaptive sensor (16bit)
- HDRC VGAX camera
 - Logarithmic response CMOS (10bit)
 - Transforms collected charge to logarithmic voltage (analog logarithm)
 - Approximation of eye-like vision
 - More details will follow

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Example Calibration

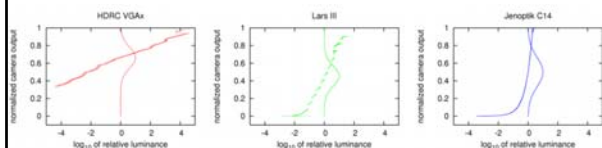


- Silicon Vision LarsIII camera
 - Locally auto-adaptive sensor (16bit)
- HDRC VGAX camera
 - Logarithmic response CMOS (10bit)
- Jenoptik C14
 - High-end CCD camera (14bit LDR, linear)

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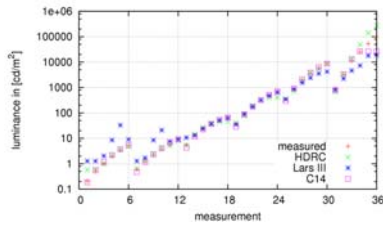
Recovered Response Curves



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Absolute Calibration



- Luminance in $[cd/m^2]$ calculated from the camera output values (at a known aperture value)

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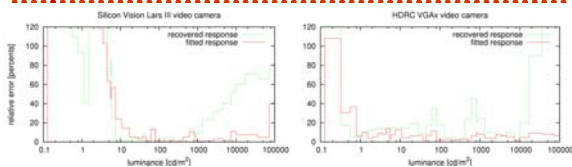
Sample Measurements

Measurement [cd/m^2]	HDRC (abs. calibration)	LarsIII (abs. calibration)	C14 (multi-exposure)
5.3	4.57	8.69	5.38
9.3	8.12	11.52	9.05
70.9	62.65	61.33	66.07
741.2	695.22	663.00	704.43
8,796.0	8,924.89	7,822.66	8,734.86
194,600.0	225,010.00	50,415.00	n/a

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Relative Measurement Errors



- HDRC camera: relative error <13% in range 1 .. 10,000 $[cd/m^2]$
- Silicon Vision: relative error <9.5% in range 10 .. 1,000 $[cd/m^2]$
- C14: relative error <7% in range 0.1 .. 25,000 $[cd/m^2]$
- Using function fit: relative error <6% for both HDR cameras

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HDR sensor vs. multi-exposure

- HDR camera
 - Fast acquisition of dynamic scenes at 25fps w/o motion artifacts
 - Typically lower resolution
 - Quality almost reaches the multi-exposure techniques
- LDR camera + multi-exposure technique
 - Slow acquisition (impossible in some conditions)
 - Higher quality and resolution
 - High accuracy of measurements

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Conclusions

HDR cameras can be used for photometric measurements.

- Function fit results in lower relative error
- Response recovery estimates the function without prior knowledge (Limited precision due to sensor noise or artifacts related to ND filters)
- Response recovery is more accessible than taking measurements required for function fit
- See section on HDR applications for example use of HDR cameras

See MPI Technical Report MPI-I-2005-4-005

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High Dynamic Range Techniques in Graphics: from Acquisition to Display

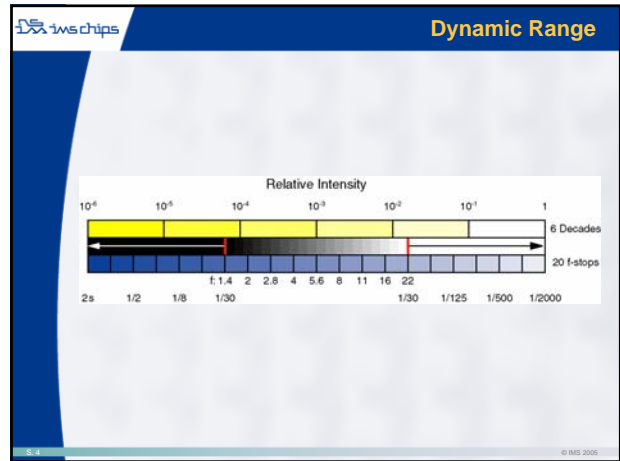
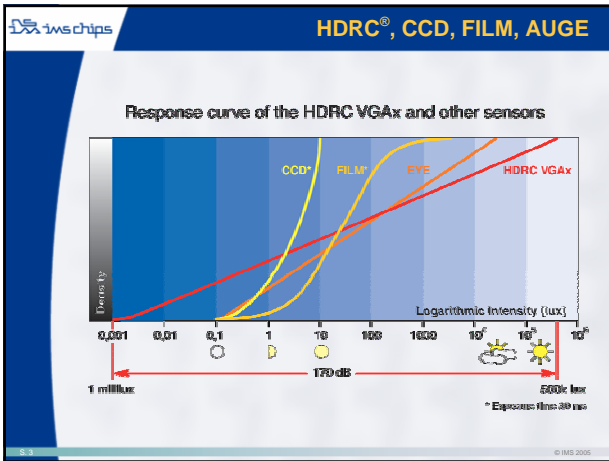
HDR Image Sensors

Prof. Dr. Bernd Höflinger
Institute for Microelectronics Stuttgart

- IT Technology
- Lithography
- ASICs
- Vision
- Learning

Imaging

IMAGING	RESPONSE	SCENE DYNAMIC RANGE	COLOR CONSTANCY
Our eyes	Logarithmic	Very high	Yes
Painting	Eye-like, logarithmic	High	Depending on the artist
Film	Pseudo eye-like, pseudo logarithmic	High	Yes
Vidicon	Linear	Small	No
CCD	Linear	Small	No
Other CMOS	Linear	Small	No
HDR	Eye-Like, logarithmic	Very high	Yes



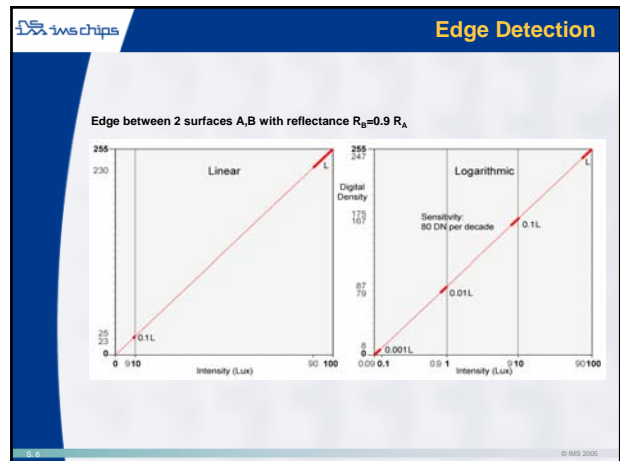
Contrast Sensitivity

Contrast Sensitivity of a Logarithmic OECF

Output N Bit	8 Bit	9 Bit	10 Bit	11 Bit	12 Bit
Input M Decades					
2 Dec	1.8	0.90	0.45	0.225	0.112
3 Dec	2.7	1.35	0.675	0.336	0.168
4 Dec	3.6	1.8	0.900	0.45	0.225
5 Dec	4.5	2.25	1.175	0.56	0.280
6 Dec	5.4	2.7	1.350	0.67	0.336
7 Dec	6.3	3.15	1.575	0.784	0.392
8 Dec	7.2	3.6	1.80	0.9	0.45

Input Dynamic Range: M Decades
Output Signal Range: N Bit

Contrast Sensitivity is the percent input change, which will be noticed as a change of 1 LSB (1DN) in the output.



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HDRC® Log-Compressing Pixel

Filed 03/24/1992 International Patents

HDRC® Front-End

HDRC® VGx Camera Front-End OCP*

1. Photodiode
2. Log Transistor V
3. Pixel capacitance $\log I_{ph}$
4. Pixel buffer
5. Multiplexer
6. Amplifier
7. Video A/D converter
8. Controller
9. Fixed-pattern correction memory

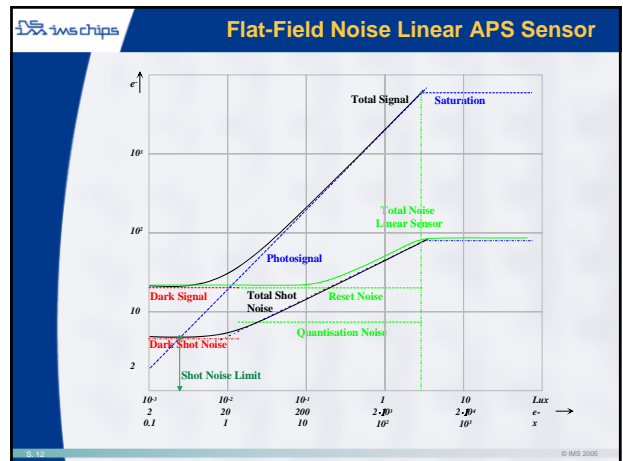
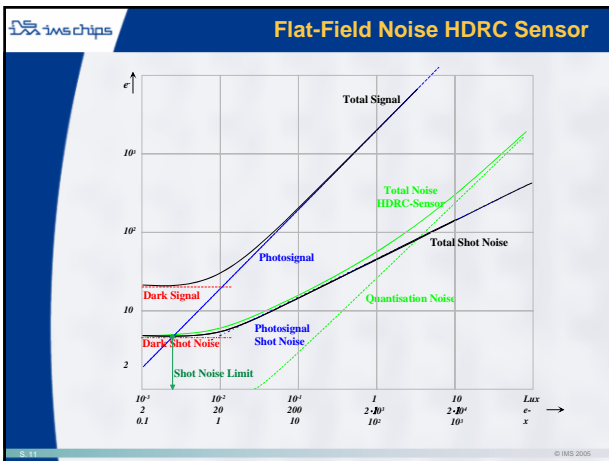
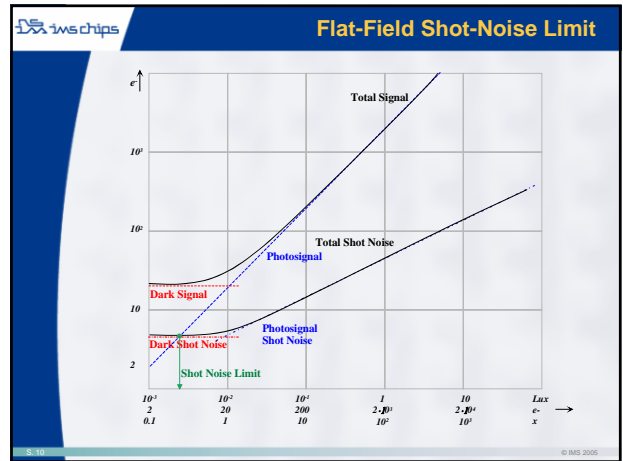
*OCP: Open-Camera Platform

Reference CMOS Pixel

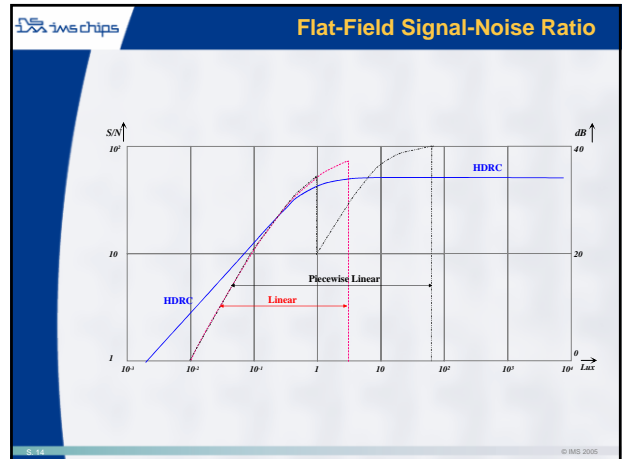
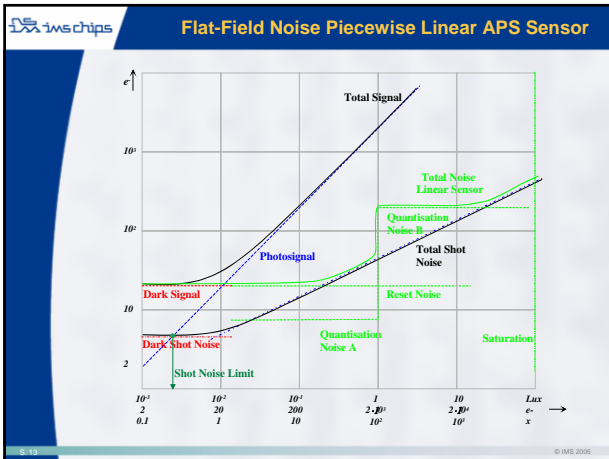
Pixel Area	(μm^2)	7.4 x 7.4
Photodiode (PD) Area	(μm^2)	5.0 x 5.0
Capacitance	(fF)	2.5
Dark Charge	(e)	20
Dark Shot Noise	(e)	4.5
Conversion Efficiency	(e/mLux)	2
Sensitivity	(DN/mLux)	0.33
Sensitivity	(V/Lux * s)	5.4
Reset Noise	(e)	20
Quantisation: (1 DN) ¹⁾	(mV)	6
	(mV)	0.4

Conditions: T = 20 °C, T_{int} = 25 ms

¹⁾ Linear 10 Bit



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HDRC® Color Constancy

Over- or Under-exposure? No Problem for HDRC®

Recorded HDRC® images displayed after offset adjustment.

HDRC® Color on the Log Scale

HDRC® color imaging benefits again from following nature's fundamentals: The R, G, B color receptors in our eyes with their individual logarithmic responses deliver signals, which are composed to provide our perception of colors. Strictly analogous, we superimpose the Log R, Log G, Log B signals directly pixel by pixel to generate color images.

The outputs of the log-compressing pixels are recorded directly as voltages $\log R(x, y)$, $\log G(x, y)$ and $\log B(x, y)$. If, in a simple model, we describe the local recorded intensity $I(\lambda, x, y)$ as the product of the irradiance $L(\lambda)$ and the object reflectances $Refl(\lambda, x, y)$:

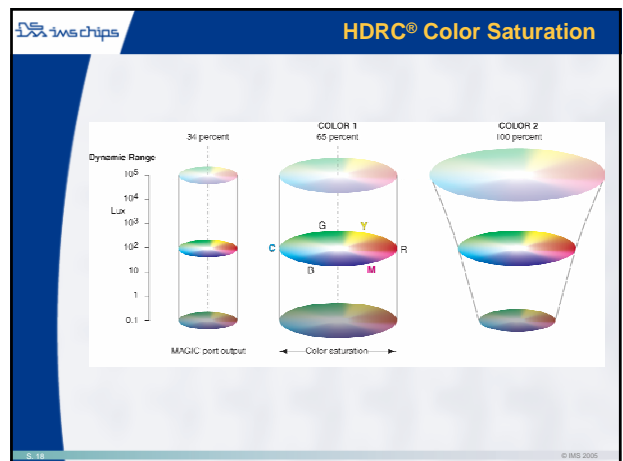
$$I(\lambda, x, y) = L(\lambda) \cdot Refl(\lambda, x, y)$$

the log intensity recorded by the HDRC imager becomes

$$\log I(\lambda, x, y) = \log L(\lambda) + \log Refl(\lambda, x, y)$$

HDR Color Management

Optical Stimulus	Electronic Output
Brightness $L(x, y)$	Lightness $L^*(x, y) = f(L) = \kappa \log L$
Brightness White L_w	Lightness White $L^*_w = f(L_w) = \kappa \log L_w$
Tristimulus Color Red X	Color Red $C_R = f(X/X_w) = \kappa_R \log(X/X_w)$
Chroma (X/L_w)	Chroma $f(X/L_w) = C_R - L^*_w$
Saturation $S_R = (X/L)$	Saturation $s_R = f(X/L) = C_R - L^*$ $L^* = (C_R + C_G + C_B)/3$ Enhanced Saturation $s^*_R = \alpha_R (C_R - L^*)$
Color $X = S_R \cdot L$	Enhanced Color $C^*_R = s^*_R + L^* = \alpha_R (C_R - L^*) + L^*$ Refinements 1) $\alpha_R = \alpha_R(L^*)$ 2) $\alpha_R = \alpha_R(\kappa_R)$



Steps towards a HDRC Color Image

- For the R, G, B pixels, record the output voltages V_R, V_G, V_B of the log-converting HDRC sensor and convert to digital numbers (DN).
 - With a grey opaque diffuser filter, shift the centers of the recorded RGB histograms to coincide = white balance.
 - Remove filter, and for each captured frame, get Min and Max of the frame histogram.
- Expand and shift all DN to fully utilize the lightness range L^*_w .
- Depending on the RGB mosaic topology, perform center-surround operations to obtain the tri-color values C_R, C_G, C_B for each pixel.
- Perform color enhancement operations to obtain C^*_R, C^*_G, C^*_B per pixel.

HDRC® Balance Memory

ONE Memory for Many Functions

Adjustment for:
 Lens Nonuniformities $T(\lambda, x, y)$
 Nonuniform Illuminance $L(\lambda, x, y)$
 Pixel Nonuniformity $FP(\lambda, x, y)$
 Spectral Sensitivity $\alpha(\lambda)$

$$V_R(x, y) = \log Ref_R(x, y) + \log L(x, y) + \log a_R + \log T_R(x, y) + FP(x, y)$$

HDRC® Illuminance Equalisation


Original HDRC® Frame Log Illuminance (Spotlight) HDRC® Frame after Log Illuminance Offset

Spotlight Illumination of the Face
 Excellent Face Recognition with HDRC®
 Improvement by Irradiance Equalisation

White and black saturation of the CCD pixels limits any gains from pre-processing

HDRC® Log Imaging

- Vision: Natural and Film
- High-Dynamic-Range Logarithmic Vision
- No Shutter-or Integration-Time
- Separating Illuminance and Features of Objects
- HDRC® sensors
 - track photon flux continuously
 - are free from control loops (with their dead times and delays)
 - absolutely cannot be blinded (white-saturated)
 - offer constant contrast resolution over many decades of grey
 - keep colors constant independent of luminance or aperture
- Illuminance Equalisation
- Robust Preprocessing
- High-Latitude Post-Production



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HDR Image and Video Compression

Karol Myszkowski
MPI Informatik

Overview

1. HDR Image Encoding
2. HDR Video Encoding
 - Luminance Quantization
 - Edge Coding
3. HDR Visible Differences Predictor
 - LDR VDP
 - HDR extensions
4. HDR Video Player demo

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Traditional RGB Image Formats

- Tailored for display devices
 - Color gamut: constrained by red, green, and blue monitor phosphors
 - Luminance encoding: often limited to 2 orders of magnitude
- Not suitable to encode color gamut and luminance of the real world scenes

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HDR Image Encodings: Requirements

- Luminance encoding:
 - 12 orders of magnitude
 - 5 orders simultaneously visible
 - Quantization error below 1%
- Full visible color gamut represented
- Possibly perceptually uniform luminance and color gamut quantization steps

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Non-lossy HDR Image Formats

- Radiance RGBE Encoding: 32 bits [Ward 1991]
 - 76 orders of magnitude, 1% luminance steps
 - Does not cover visible gamut
 - Perceptually non-uniform quantization steps
- LogLuv (part of TIFF library): 32 bits [Larsen 1998]
 - 36 orders of magnitude, 0.3% luminance steps
 - 16 bits log luminance – very conservative, better perceptual uniformity still possible
 - Covers full visible gamut
 - 8 bits for each of perceptually uniform CIE u^*v^* color coordinates

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Non-lossy HDR Image Formats

- OpenEXR: 48 bits [Bogart et al. 2003]
 - 9.6 orders of magnitude, 0.1% luminance steps
 - Covers full visible gamut
 - Perceptually non-uniform color representation
 - 16-bit floating point
 - Suitable for extensive image operations which may result in error accumulation
 - *De facto* industrial standard
- Lossy OpenEXR soon

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HDR JPEG [Ward and Simmons 2004]

- Backward compatible JPEG encoding
 - Tone mapped original (TM) accompanied by a ratio image (RI) needed to recover full HDR image
 - RI carried in a subband of a standard 24-bit RGB format

$HDR\ image = TM * RI$

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HDR JPEG [Ward and Simmons 2004]

- The ratio image RI is often downsampled to RI_d
- Distortion reduction
 - Pre-correction of foreground image $TM' = \frac{HDR}{RI_d}$
 - Post-correction of ratio image $RI' = RI_d \cdot \left[\frac{Lum(TM)}{Lum(TM_d)} \right]^\sigma$ where $\sigma = \frac{var(RI_d)}{var(Lum(TM_d))}$

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HDR MPEG Encoding [Mantiuk et al. 2004]

- Detail level 1: Input & Output

- White: MPEG
- Orange: HDR Encoder

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HDR MPEG Encoding [Mantiuk et al. 2004]

- Detail level 2: Color Transform

- White: MPEG
- Orange: HDR Encoder

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HDR MPEG Encoding [Mantiuk et al. 2004]

- Detail level 3: Edge Coding

- White: MPEG
- Orange: HDR Encoder

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Encoding of Color

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Encoding of Color

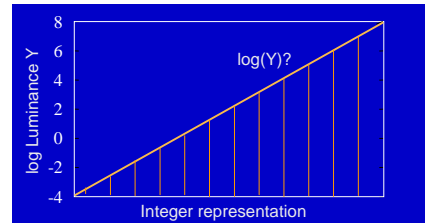
- How to represent color data?
 - Floating Points – ineffective compression
 - Integers – ok, but require quantization
- How to quantize color data?
 - Quantization errors < threshold of perception
 - Use uniform color space ($L^*u^*v^*$, $L^*a^*b^*$) [Ward98]
 - Find minimum number of bits
- Color (u^*v^*) – 8 bits are enough

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Encoding of Luminance

- How to quantize luminance?
 - Gamma correction? Logarithm?

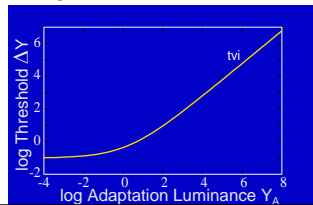
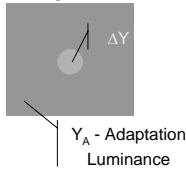


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Threshold Versus Intensity

- Psychophysical detection measurements
 - The smallest perceivable difference ΔY for a certain adaptation level Y_A
 - tvi [Ferwerda96, CIE 12/2.1]



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Luminance Quantization

- Align quantization errors with thresholds of perceivable contrast using $tvi(Y_A)$

$$\text{quantization } \psi : L_p \rightarrow Y \left[\frac{\text{cd}}{\text{m}^2} \right] \text{ where } L_p = [0, 2^{n_{bits}} - 1]$$

$$\text{error} : e_{\max}(l) = \max \{ |\psi(l + 0.5) - \psi(l)|, |\psi(l) - \psi(l - 0.5)| \}$$

$$e_{\max}(l) \approx 0.5 \frac{d\psi(l)}{dl} \quad (\text{Taylor series expansion})$$

$$e_{\max}(l) = \frac{tvi(Y_A)}{f} \quad (\text{psychophysics : JND scaled by } f)$$

$$\frac{d\psi(l)}{dl} = 2 \cdot \frac{tvi(\psi(l))}{f}$$

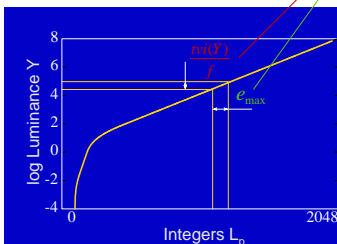
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Luminance Quantization

Just below threshold of perception

Maximum quantization error



$$\frac{d\psi(l)}{dl} = 2 \cdot f^{-1} \cdot tvi(\psi(l))$$

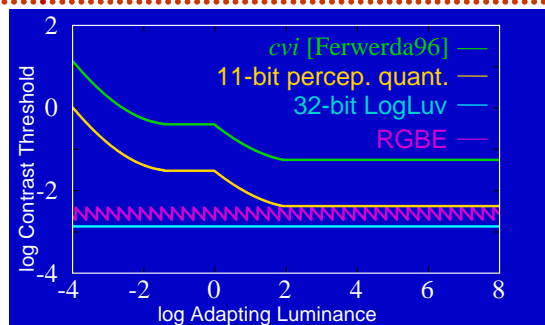
$l - L$ in L_p space
 $\psi(l) - L_p$ to Y mapping
 f - threshold decrease

- Capacity function [Ashikhmin02]
- Grayscale Standard Display Function [DICOM03]
- **10 – 11 bits are enough**

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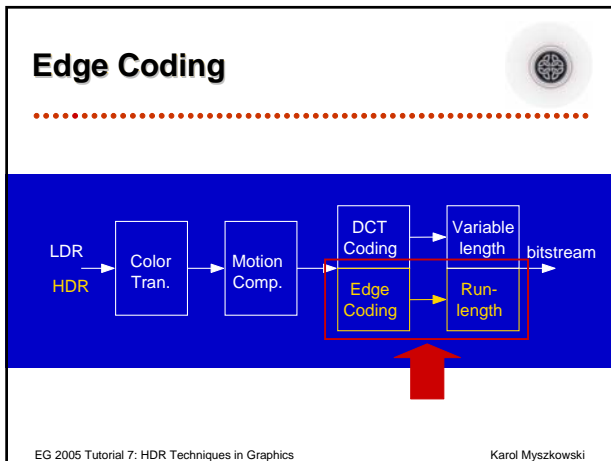
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Luminance Quantizations Comparison



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Edge Coding: Motivation

- HDR video can contain sharp contrast edges
 - Light sources, shadows
- DCT coding of sharp contrast may cause high frequency artifacts

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Edge Coding: Solution

- Solution: Encode sharp edges in spatial domain, the rest in frequency domain

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Edge Coding: Algorithm

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Results

- 2x size of tone-mapped MPEG-4 video
- 20-30x saving compared to intra-frame compression (OpenEXR)

Method	Bit-stream Size
MPEG-4	0.55
HDR Enc.	1
OpenEXR	27

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Example Application: HDR Video Player

- Tone mapping adjusted to display device
- Inspecting various luminance ranges with a linear luminance mapping
- Physically based post-processing effects: blooming, motion blur, night vision
 - Require HDR information
 - Computed on-the-fly by graphics hardware
 - Can be scripted through annotations in video stream

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HDR Video Player: Glare

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HDR Video Player: Motion Blur

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HDR Video Player: Night Vision

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Summary: HDR Video Compression

- Modest changes to MPEG-4
 - $L_p u'v'$ color space
 - Luminance quantization (10-11 bits)
 - Edge coding
- Backward compatible HDR MPEG-4?

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Visible Difference Metric

- Can the human eye see the differences between two images?

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Application Examples

- Lossy image compression and broadcasting
- Design of image input/output devices
 - scanners, cameras, monitors, printers
- Watermarking
- Computer graphics, medical visualization

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Subjective vs. Objective Methods

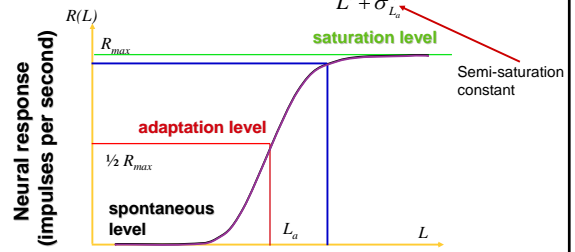
- Subjective methods involving human subjects
 - Very costly
- Simple objective metrics e.g. RMS Error
 - Not reliable
- Basic characteristics of the Human Visual System (HVS) must be modeled to improve difference prediction reliability:
 - + Luminance adaptation
 - + Contrast sensitivity
 - + Visual masking

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Photoreceptor Response

Michelis – Menten Equation : $R(L) = \frac{L^n}{L^n + \sigma_{L_a}^n} R_{max}$ $n \approx 0.74$



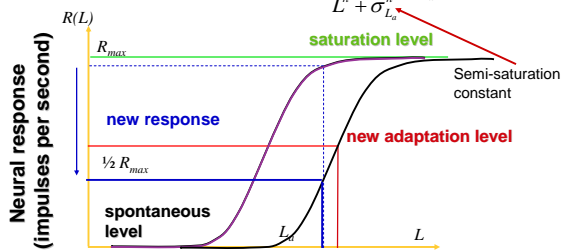
Luminance of light falling on receptive field's center

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Photoreceptor Response

Michelis – Menten Equation : $R(L) = \frac{L^n}{L^n + \sigma_{L_a}^n} R_{max}$ $n \approx 0.74$

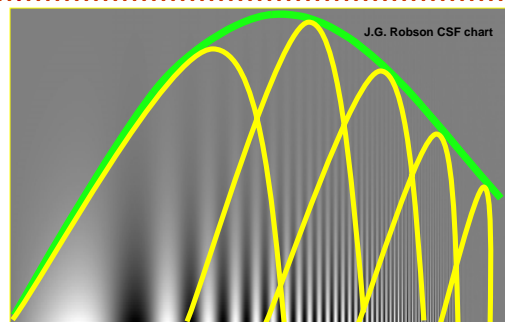


Luminance of light falling on receptive field's center

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Contrast Sensitivity Function

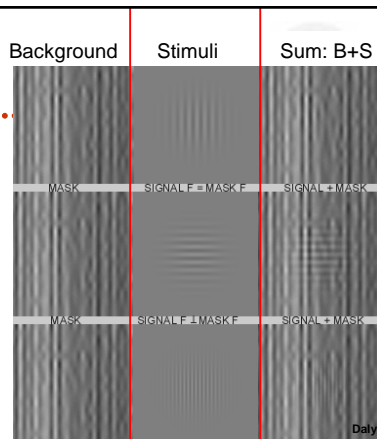


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Visual Masking

- Strong masking: similar spatial frequencies
- Weak masking: different orientations
- Weak masking: different spatial frequencies

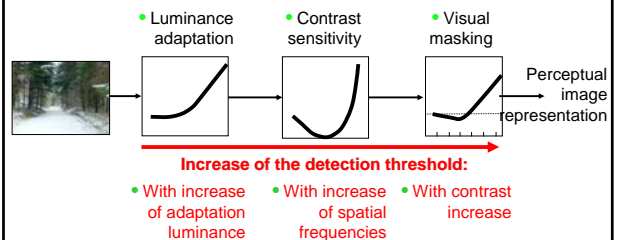


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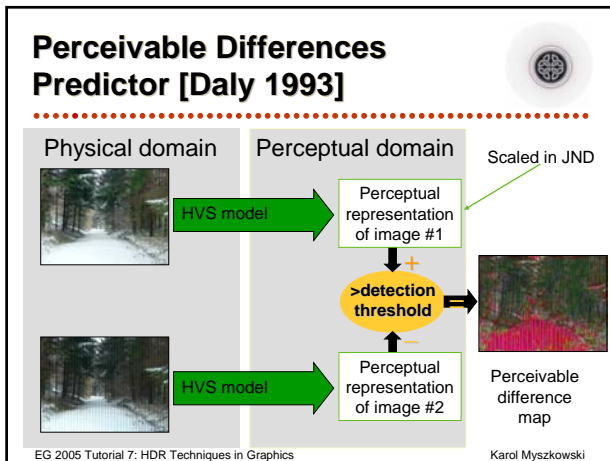
Typical HVS Model

Detection of perceivable differences between images depends on the following characteristics of the HVS:

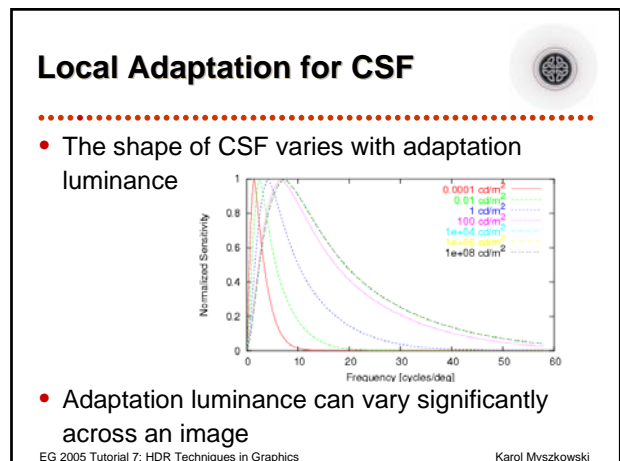
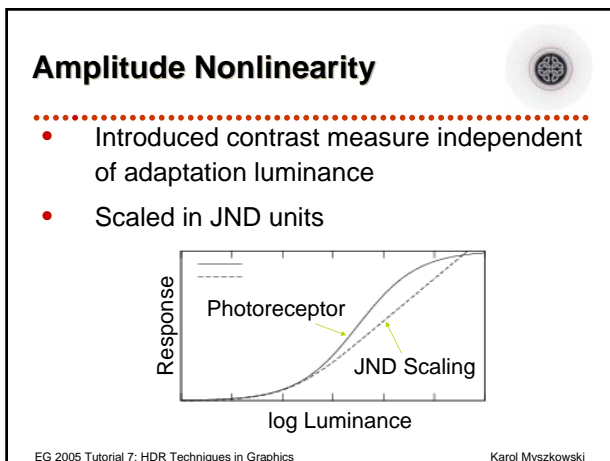
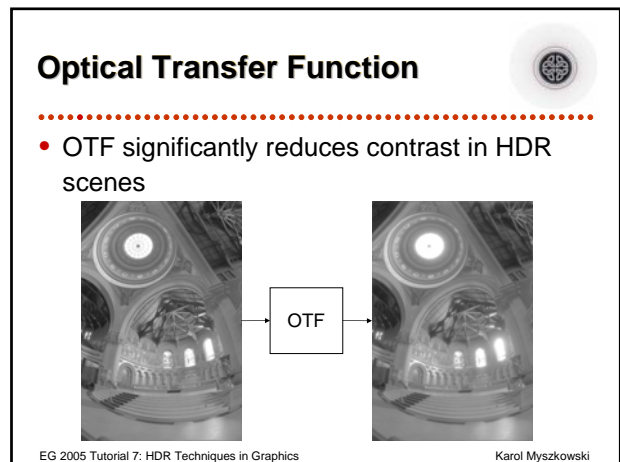
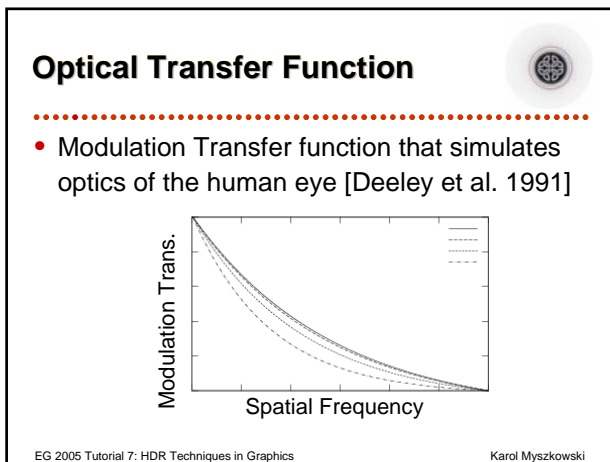


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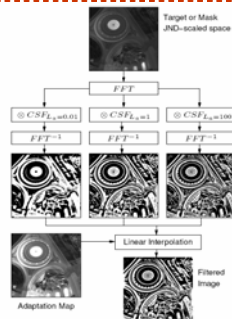


- ### HDR VDP – Extensions [Mantiuk et al. 2005]
- Optical Transfer Function
 - Glare effect important for high contrasts
 - JND scaled contrast
 - Contrast measure that does not depend on adaptation luminance
 - Locally adaptive CSF
 - Instead of global adaptation for the whole image
- Assumption: The eye can adapt to luminance of very small patches (to a single pixel)
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Local Adaptation for CSF

- 1. Use different CSF for filtering each part of an image
- 2. Interpolate filtered images depending on adaptation luminance [Durand03]



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Calibration

- An experiment conducted on an HDR display to find subjective difference probability map
- HDR VDP parameters optimized to fit closely subjective data

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Calibration: Experiment

- Subjects were to mark visible differences using rectangular blocks
- Results averaged across subjects
 - fuzzy detection probability map

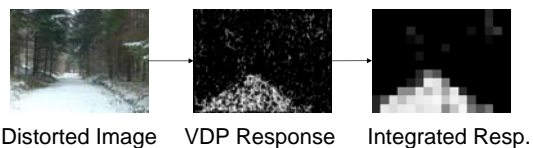


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Calibration: Data Fitting

- HDR VDP response converted to format of the subjective data



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Summary: HDR VDP

- Objective visual difference metric
 - Not limited to existing display technology
 - Predicts changing sensitivity in bright and dark regions of an image
 - Small performance overhead
- Applications
 - New display technology (HDR display)
 - Assessment of visibility for varying luminance conditions

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Acknowledgments

- I would like to thank Rafal Mantiuk for sharing with me some slides used in this presentation.
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- HDR Camera HDRC(R) VGax courtesy of IMS CHIPS www.hdrc.com



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Tutorial 7
High Dynamic Range Techniques in Graphics: from Acquisition to Display
High Dynamic Range Displays



Wolfgang Heidrich and Matthew Trentacoste
University of British Columbia

Part 1

- Develop HDR display
 - Use results on visual perception
 - Easy to build
 - Easy to calibrate
 - Address software issues
 - Make it commercially viable
 - Sunnybrook Technologies



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Our Work

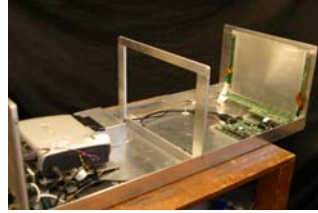
- Two setups:
 - Projector-based prototype
 - Good for evaluating principle
 - Experiment with design parameters
 - LED-based version
 - More practical/economic design
 - Commercially available

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First Setup: Projector/LCD Panel

- Hardware setup:
 - Remove backlight from LCD panel
 - Shine image from video projector onto back of panel
 - (Fresnel lens for focusing)
 - Multiplies dynamic range of LCD and projector
- Measured:
 - Contrast: 50,000:1
 - Intensity: 2,700 cd/m²





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Screenshots



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Screenshots



- Photographs taken with 4 stops different exposure time

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Screenshots



- Photographs taken with 4 stops different exposure time

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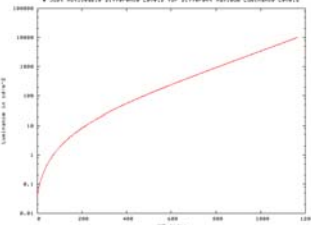
Initial Discussion

- Advantages:
 - Relatively easy to build
 - Works!
- Issues:
 - Have 8bit for each of LCD, projector, but not independent!
 - Quantization artifacts?
 - Alignment of projector/panel very hard
 - Changes during operation (heat!)
 - How do we render for this?

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Quantization?


- Just Noticeable Differences
 - Results from psychophysics [Barten 2001]:
 - Number of intensity levels discernable for given intensity range
 - Predicts about 950 levels for this display
 - These are easy to create using combinations of projector/LCD values



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Alignment Problems

- Problem:
 - Have to align projector pixels with LCD pixels at sub-pixel accuracy
 - Impossible (precise alignment changes due to heat deformation)
 - Any misalignment creates moiré patterns
- Solution:
 - Blur the projector image
 - Low-frequency image – precise alignment not necessary



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Software Issues

- Rendering:
 - Have to split floating point image into
 - projector contribution
 - LCD panel contribution
 - Have to compensate for blur in projector
 - Many ways to do this, since projector and LCD values not independent!

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Discussion

- Advantages:
 - Relatively easy to build
 - Works well in lab settings
- Disadvantages:
 - Heat
 - Power consumption
 - Size
 - Needs to be re-calibrated every few days
 - Does not take very long, but annoying

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Second Setup



- Idea: Replace projector with array of LEDs
 - Very few (about 1000) LEDs sufficient
 - Every LED intensity can be set individually
 - Very flat form factor (fits in standard LCD housing)
 - Calibration issues simpler
 - Less heat/power consumption
 - LEDs are most often not at highest intensity

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Second Setup



- Results:
 - Intensity: 8,500 cd/m², contrast >150,000:1
- Issue:
 - LEDs larger than LCD pixels
 - This limits maximum *local* contrast
 - Is this a problem?

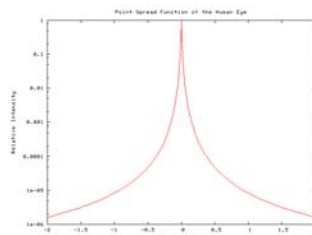
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Local Contrast and Human Perception



- Maximum perceivable contrast
 - Globally very high (5-6 orders of magnitude)
 - This is why we create these displays!
 - Locally pretty low: 150:1
 - Point-spread function of human eye



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Local Contrast and Human Perception

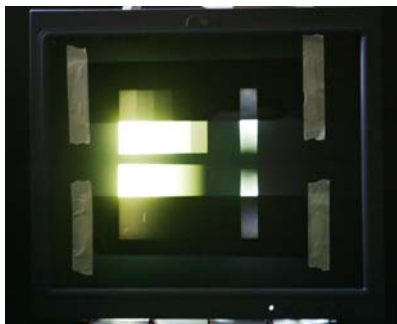


- Consequence:
 - High contrast edges above 150:1 are not seen at full contrast
 - Light scatters from light side to dark side
 - Rendering:
 - Choose LED intensity for bright side
 - compensate as best possible for dark side in LCD panel
 - LCD panel has contrast of 400:1
 - Enough to push error below perceivable limit

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Rendering challenges



- Display image data in “gamut”
 - Intensities and gamut within that of display
 - Produce “best” displayed image
- Map image out of displayable range into “gamut”
 - Intensities or gamut exceed that of display
 - Tonemap / color space transformation to preserve impression
- Assume for now, image is within displayable range

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Rendering



- Input
 - An image containing scene-referred information
 - Absolute intensities
 - Known color space
- Output
 - A set of LED values and LCD panel image that yield the “best” displayed image
 - Output-referred format targeted to a specific display

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Defining “Best”



- Best has many definitions
 - Different sets of constraints
 - Largest dynamic range
 - Minimum error
- Inherent tradeoffs between range and quantization
 - Bits of the LCD panel can be divided between increasing the dynamic range and blur correcting
 - Larger dynamic range means less correction
- Application dependent
 - Casual viewers and experts have different requirements

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Different constraints



- Maximize use of available dynamic range
 - Panel contributes to dynamic range
 - Less bits for correction
- Minimize the error in reconstruction
 - Panel only used for correction
 - Desire LCD at 50%, have most bits to correct above / below
- Conserve energy to stay within power constraints
 - DR37 would pull 4000 W if driven at full
 - Standard breaker is only 1500 W

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Naïve approach



- Make as few assumptions as possible
 - Non-linear solver
 - Have function $F(\text{LCD, LEDs}) = \text{image}_{\text{displayed}}$
 - Accurately simulate displayed image given driving levels
 - Minimize Error($\text{image}_{\text{original}} - \text{image}_{\text{displayed}}$)
 - Huge and slow
 - $m+n$ inputs, m outputs
 - $m = \text{num LCD pixels}$, $n = \text{num LEDs}$
 - What does error function look like?

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Computing error



- Error in perceptual units
 - Look to psychophysics
 - Nonlinear quantization of luminance
 - JND-space comparison
 - Ocular scatter
 - Pointspread of eye, contrast sensitivity function (CSF)
 - Similar to HDR Visible Differences Predictor [Mantiuk 2005]



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Algorithm Overview

- Given image
- Choose optimal LED values
- Simulate the backlight
- Correct original image for blurry backlight
- Write out to the display controllers

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Algorithm Process

- Given image
- Simulate the backlight
- Correct original image for blurry backlight

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Optimization

- Pixels are linearly independent of each other
 - Pick the LCD value that blur corrects the best
 - Reduce problem to finding "best" backlight (LED values)
- Backlight is low frequency due to optical package
 - Can work on a low resolution of backlight
 - Filter and down sample to get an ideal LED image

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Optimization

- Significant reduction in size of system
 - What was roughly a 2 million x 2 million matrix (for 1920x1080) down to roughly 1500 x 1500 matrix
- Sub-optimal choice of LEDs can be fixed with LCD
 - Don't even have to do that good a job at the hard part

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Simulation Accuracy

- LCD panel can resolve problems with LED choice
 - But not without a price
 - The worse the LED values, the more of the panel's driving values are needed for correcting the backlight
 - Larger error in reconstruction, or less dynamic range
- Simulation quality
 - High quality simulation of backlight required produce acceptable final image without artifacts
 - Accuracy → calibration → measurement
 - Many attributes of the display must be measured to ensure that the simulation results correct

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Required Measurements

- Preprocessing
 - Intensity range of display
 - Color space of LCD panel and backlight
- Simulation
 - LEDs / optical package pointspread
 - Positions and offset of LEDs
- Output
 - LED response to linearize
 - Individual LED characteristics (intensity)
 - LCD response to linearize

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Techniques



- Weighted average
 - Each LED is determined by a weighted average of it and its neighbors
 - Similar to 1 step of an iterative solver
- Error diffusion
 - Each LED tries to minimize the remaining error
 - Greedy approach
- Non-linear solver
 - Mostly to provide ground truth to compare against

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Weighted Average



- Directly address LED crosstalk
 - Each LED contributes light to a large number of pixels
 - Multiple LEDs required to reach top intensity
 - Given a desired backlight image
 - Try to account for light contributions from other LEDs
 - Weight according to pointspread
 - $LED_i = desired_i * total_illum - \sum (LED_j * w_j)$

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Error Diffusion



- Greedy approach
 - Iterate over all LEDs
 - For each LED, choose the value that minimizes the error with the image to that point
 - Subtract out contribution for chosen value and use resulting image as input for next LED
 - Direct solution
 - $\min \sum (I(x,y) - P(x,y)w)^2$
 - $w = \sum(2IP) / \sum(P^2)$

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Blur correction



- Given LED values simulate backlight
 - Direct evaluation of pointspread model possible if number of LEDs sufficiently small (FPGA method)
 - Represent each LED as a texture splat modulated by its driving level (GPU method)
- Correct original image
 - LCD panel modulates backlight
 - Divide original image by backlight simulation to get blur corrected image

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Future Work



- HDR tonemapping / color space transformation
 - All the same constraints on LDR still apply, only loosened
 - How well do current practices work and how should they be modified?
- Help with new psychophysical models
 - Adaptation of viewer
 - Many applications assume infinitesimally small area of adaptation
 - Does something displayed 25% as bright as the original still have the same appearance as long both are driving adaptation?
 - What else?


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Impression of a Scene



- Humans can differentiate over 12 million colors
- Can only identify about 300
- What can we learn in reproducing HDR images?
 - Does accurately reproducing exact intensity matter
 - Is the right ratio between 2 intensities sufficient
 - Or is "brighter" and "darker" sufficient
- Study the human visual system to tell how much is enough

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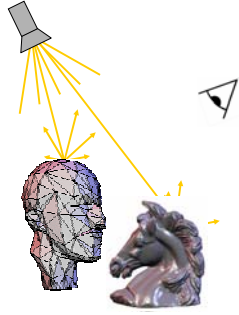
Tutorial 7
High Dynamic Range Techniques in Graphics: from Acquisition to Display

HDR Applications
Image-based Measurements of Object and Material Properties

Michael Goesele
MPI Informatik

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Scene Acquisition in Computer Graphics



- object geometry
- emission patterns of light sources
- reflection properties of objects
 - local light reflection (BRDF)
 - subsurface light transport (BSSRDF)
- ...

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Sources of Dynamic Range

- diffuse materials reflect between 0.5% and >90% of incoming light
- specular highlights much brighter
- lit regions vs. in shadow regions
- moonless night vs. sunny day

→ high dynamic range mainly caused by illumination effects

- typical for reflectance measurement applications
- simultaneous vs. sequential dynamic range

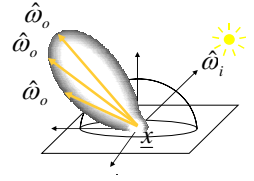
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Surface Reflectance (BRDF)

- a BRDF (bi-directional reflectance distribution function)

$$f(\hat{\omega}_o, \underline{x}, \hat{\omega}_i)$$

yields the fraction of reflected to incident radiance at one point for any pair of directions.




- Our goal: reconstruct the BRDF **on the entire surface**, not just in a few selected points (gonio-reflectometer approach)

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Measurement of Spatially Varying BRDFs


- Acquisition of a real world object (multiple materials)
 - several images with varying light source positions are captured
 - surface points are grouped into clusters of similar reflection properties
 - individual BRDFs are fitted for each cluster



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Acquisition Setup

- 3D scanner
- digital camera (high dynamic range)
- point-light source
- dark room (reduces influence of the environment)
- calibration targets (checkerboard, metal spheres)



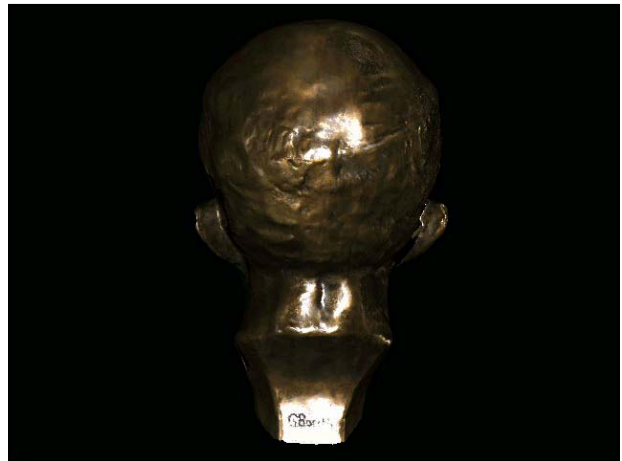
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Results



H. P. A. Lensch, J. Kautz, M. Goesele, W. Heidrich, H.-P. Seidel: Image-Based Reconstruction of Spatial Appearance and Geometric Detail. ACM Trans. Graphics 22(2), p. 234-257, 2003.

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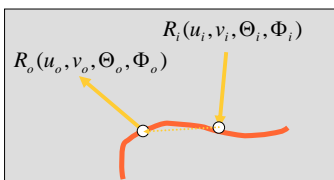
Subsurface-Scattering Properties (BSSRDF)

- bidirectional scattering-surface reflectance distribution function (BSSRDF) [Nicodemus 1977]
 - reflected radiance per incident flux for each pair of surface locations and directions
 - 8 dimensional function

$$\rho(R_i; R_o) = \rho(u_i, v_i, \Theta_i, \Phi_i; u_o, v_o, \Theta_o, \Phi_o)$$

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Subsurface-Scattering Properties (BSSRDF)




$$\rho(R_i; R_o) = \rho(u_i, v_i, \Theta_i, \Phi_i; u_o, v_o, \Theta_o, \Phi_o)$$

- very general representation
- almost impossible to acquire

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Translucent Objects




- light is scattered through the object
- incident illumination smoothed due to diffuse scattering inside media
- imperfections can be masked by scattering behavior

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Translucent Objects

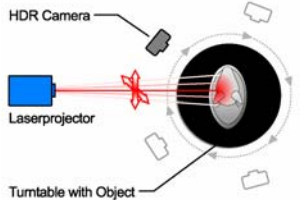
- multiple scattering (almost) independent of incident light direction
- example: alabaster block illuminated by a laser from the left



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BSSRDF of Translucent Objects

- DISCO acquisition approach
 - illuminate individual surface points
 - store impulse response of the object



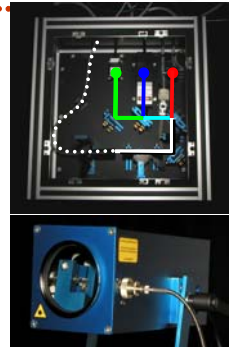
M. Goesele, H. P. A. Lensch, J. Lang, C. Fuchs, H.-P. Seidel: DISCO - Acquisition of Translucent Objects. ACM Trans. on Graphics (Proc. SIGGRAPH 2004), 2004.

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Laser Projector

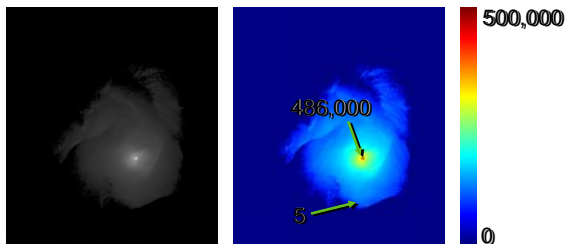
- three lasers
 - (635nm, 532nm, 476nm)
 - ~10mW optical power
- constancy
- resolution 4096x4096 steps
 - step size < 0.1 mm on object possible
- repeatable



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Inherent High Dynamic Range

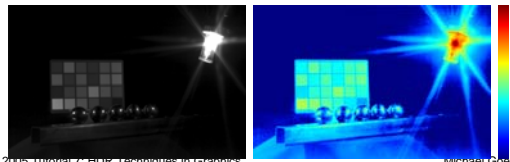
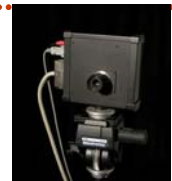


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HDR Video Camera

- Silicon Vision Lars III
- monochrome HDR
- dynamic range > 1:1,000,000
- acquisition with 15 fps



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Results

- 500,000 – 1,000,000 (!) images acquired
- images yield entries in a throughput factor matrix
- all views where the same point is illuminated yield one column of the point-to-point throughput matrix
- resample images into hierarchical model
- see [Goesele et al. 2004] for details

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Results



photograph



rendering

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Results



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informatik


Tutorial 7
High Dynamic Range Techniques in Graphics: from Acquisition to Display

Virtual Scene Re-lighting
CAVE System for Car Interior Modeling

Kirill Dmitriev, Thomas Annen, Grzegorz Krawczyk,
 Karol Myszkowski, Hans-Peter Seidel
 MPI Informatik

Motivation

Predict impact of quickly changing environment lighting conditions on the ease of car navigation



Target application:

- VR centers of car manufacturers

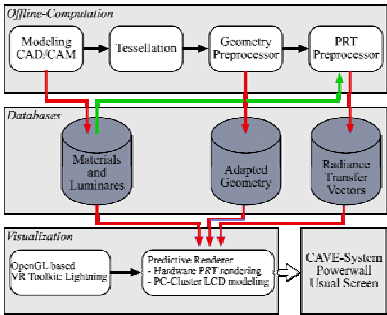
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System Requirements

- General
 - Illumination with HDR video environment map
 - Light changes often and abruptly
- PRT for the car interior
 - Geometry does not change so precomputation possible
 - High performance required but approximation acceptable
- Final gathering for the LCD panel
 - Precise computation of the LCD appearance is required

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Architecture



The diagram shows a three-tier architecture. The top tier, 'Offline-Computation', includes 'Modeling CAD/CAM', 'Tessellation', 'Geometry Preprocessor', and 'PRT Preprocessor'. The middle tier, 'Database', contains 'Materials and Luminaires', 'Adapted Geometry', and 'Radiance Transfer Vectors'. The bottom tier, 'Visualization', includes 'OpenGL-based VR Toolkit: Lighting', 'Preliminary Renderer - Hardware PRT rendering - PC-Cluster LCD modeling', and 'CAVE-System Powerwall Usual Screen'. Arrows indicate data flow between these components.

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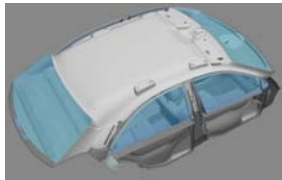
Acquisition of Environment

- Real-world driving scenarios
 - Tunnels, sunset, city driving, highways, etc
- Two HDR video cameras with fisheye lenses that capture:
 - Environment map
 - Windshield image
- Results in a complete data set for CAVE

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Efficient Rendering with PRT



- Car geometry is two-sided
- Only the rays going through the windows contribute to SH coefficients

Store SH coefficients only for inside:

- Higher performance
- Lower memory use

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Computing the LCD Panel

Use final gathering to compute the color for each texel.

- Ray hits the window
→ sample environment map
- Ray hits car geometry
→ query PRT for luminance at that point
- Importance sampling from known BRDF
- Emission computed for the given observer position
- Quality improves if position unchanged



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Tone Mapping

- HDR data requires tone mapping
- Luminance adaptation required for temporal coherence
- Adaptation level influenced by a 10° foveal region (head tracking provides the look-at point in the CAVE)



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Video Demonstration



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Results

Real-world driving scenarios used to illuminate the car interior and predict the ease of the navigation panel observation.

- Efficient global illumination solution for CAVE VR applications involving static geometry and dynamic environment lighting.
- Full image tone mapping with temporal adaptation
- Car model contains approx. 500K triangles
- Visualization frame rate ~10fps

K. Dmitriev, T. Annen, G. Krawczyk, K. Myszkowski, and H.-P. Seidel
A CAVE System for Interactive Modeling of Global Illumination in Car Interior
ACM Symposium on Virtual Reality Software and Technology, 2004

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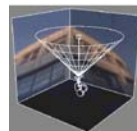


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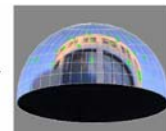
Interactive System for Dynamic Scene Lighting Using Captured Video Environment Maps

Vlastimil Havran, Miloslaw Smyk, Grzegorz Krawczyk,
Karol Myszkowski, Hans-Peter Seidel
MPI Informatik, Szczecin University of Technology

System Motivation



Illumination Acquisition



Light Sources Computation

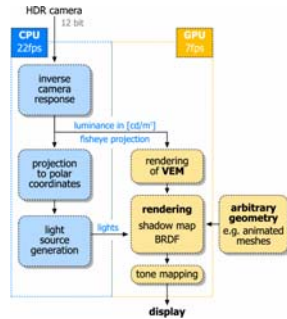


Rendering (GPU) (+Compositing)

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System Overview



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Illumination Acquisition



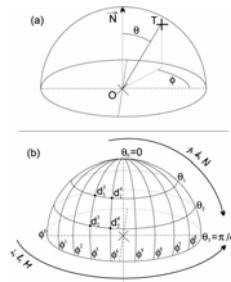
- Source of data: HDR camera
 - 12bits logarithmic response
 - 8 orders of magnitude dynamic range
- Fish-eye lens
- Resolution 640x480
- Photometric calibration necessary

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Video Environment Map

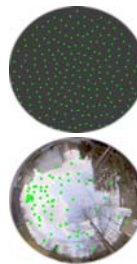
- HDR image on hemisphere defined by meridians and parallels
- Extension to time domain
- Luminance corresponds to the probability density function on the hemisphere (grid points)



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Importance Sampling Properties

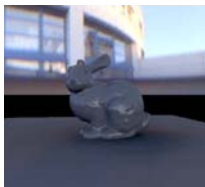


- Arbitrary number of directional light sources
- The same energy for each light source
- Progressive light source sequence
- Local blue noise properties
- Small memory requirements
- Real-time performance
- Dependence on the surface normal
- Energy and position of light sources processed with FIR filters

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Rendering

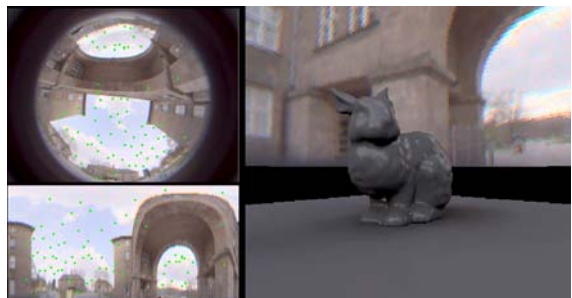


- GPU used - NVidia GeForce 6800GT
- Shadow maps tiled in large textures
- Invisible light sources reduction enabled by progressiveness of light source sequence
- Quality improvement for glossy BRDFs
- Other issues: clustering and color estimation

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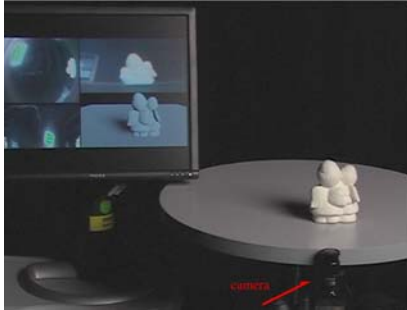
Results – Snapshots & Video



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Results – Mixed Reality



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Results

System pipeline from HDR acquisition to rendering

- Real-time computation of light sources with many properties useful for rendering
- Performance 5-10 FPS for 320x240 pixels
- Principles also useful for CPU rendering systems
- Possible applications in mixed and virtual reality (virtual studio systems)

V. Havran, M. Smyk, G. Krawczyk, K. Myszkowski, H.-P. Seidel
Interactive System for Dynamic Scene Lighting using Captured Video Environment Maps
Proceedings of 16th Eurographics Symposium on Rendering, 2005

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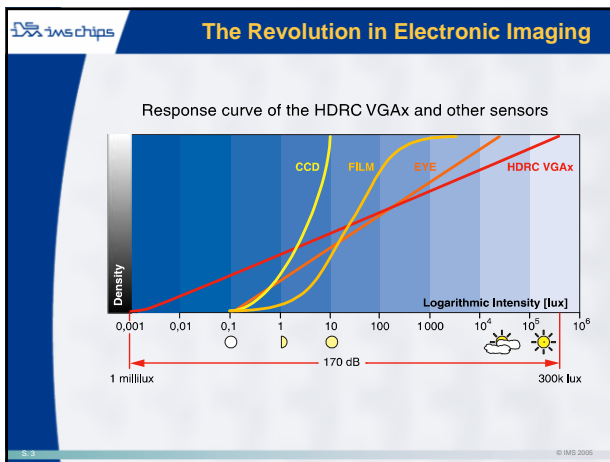
Application Examples in Automotive Industry and Computer Vision

Prof. Dr. Bernd Höfflinger
Institute for Microelectronics Stuttgart

- IT Technology
- Lithography
- ASICs
- Vision
- Learning

HDRC® Log Imaging

- Vision: Natural and Film
- High-Dynamic-Range Logarithmic Vision
- No Shutter-or Integration-Time
- Separating Illuminance and Features of Objects
- HDRC® sensors
 - track photon flux continuously
 - are free from control loops (with their dead times and delays)
 - absolutely cannot be blinded (white-saturated)
 - offer constant contrast resolution over many decades of grey
 - keep colors constant independent of luminance or aperture
- Illuminance Equalisation
- Robust Preprocessing
- High-Latitude Post-Production



Sobel Operator HDRC vs. CCD

	CCD	HDRC
Original Image		
Sobel Operator		

Courtesy: OMRON

Vision in Traffic

- 95 Percent of all decisions are based on visual information
- Human error, fatigue and distraction are major causes of accidents
- Machine vision can provide early warning for driver
- Night vision is ready to help drivers and to protect pedestrians, bikers, etc.
- Electronic vision offers big improvements for ageing driver population
- PROMETHEUS initiated major vision effort in Europe 1987
- Volume Appearance of "Eyes on Wheels" 2006/07

Electronic Eyes on Wheels

Traffic Signs
Night Vision
Road Hazard
Lane Following
Intelligent Cruise
Collision Avoidance
Intelligent Headlights

Cross Traffic and Side Impact Warning

Rear View Lane Change

Front-Seat Occupation
Distraction and Fatigue Warning
Driver Identification

Parking Aid
Dead Angle View

2010 ca. 40 Billion Euro

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Night Vision: The Challenge

Scenario with permanent infrared high beam

© IMS 2005

HDRC® Night Vision – Safe In Any Scene

CCD

HDRC

Fast motion at low light levels presents fundamental problems for all imagers, which need exposure (or integration) time to generate an image. HDRC pixels track the photon flux continuously. They produce sharp contours and texture under any lighting and speed conditions.

© IMS 2005

Hella Light Tunnel I

Car with high beams at 80 m and pedestrian at 100 m

Scenario illuminated with low beam and permanent infrared (NIR) high beam

2001

In cooperation with HELIX

© IMS 2005

Hella Light Tunnel II

Example for display mode: edge-enhanced features

Scenario illuminated with permanent infrared (NIR) high beam

2001

In cooperation with HELIX

© IMS 2005

Turn-On of Headlight 3 Frames

CCD	HDRC
0.0 sec	
0.5 sec	
1.0 sec	

© IMS 2005

Airport Sun, Fog, Night

HDRC® Camera-Guided Aircraft Docking

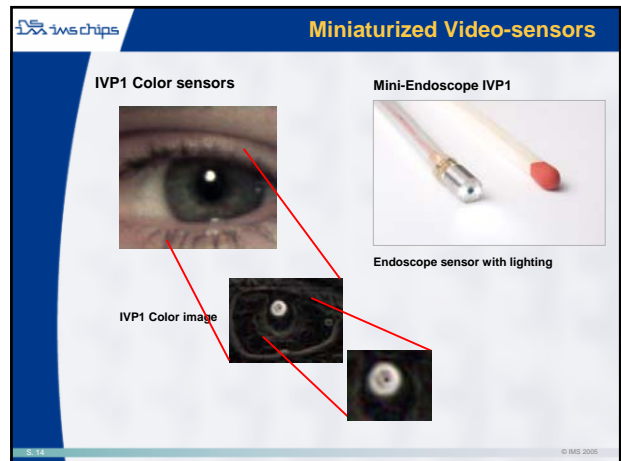
High Dynamic Range
High Sensitivity
High Contrast Resolution
One Camera Setting for All

Courtesy: Honeywell Airport Systems and Gevec

Billund
Brussels
Dresden
Hannover
Leipzig
Beijing
Seoul

SUN
FOG
NIGHT

© IMS 2005



HDR Applications: References

- B. Höfflinger: Vision Chips make Driving Safer. Europhotonics, vol. 6 (4), pp. 49 – 51, June 2001
- P. M. Knoll, H. Winner and R. Kallenbach: Surround Sensing – Collision Warning Systems and Vehicle Guidance. ATA Journal (Associazione Technica Dell'Automobile, Italia), vol. 54 (11/12), pp. 419 – 425, November 2001
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- A. Arena, M. Boulougoura, H. S. Chowdrey, P. Dario, C. Harendt, D.-M. Irion, V. Kodogiannis, B. Lenaerts, A. Menciassi, R. Puers, C. Scherjon, D. Turgis: Intracorporeal Video Probe. ICMCC Conf. Int'l Council on Medical and Care Computnet, Den Haag, NL, 8 pp., June 2005

See also

www.hema.de	www.selector.de
www.iat.uni-bremen.de	www.hdr.com
www.de.bosch.com	www.gevitec.com
www.ivp.ims-chips.de	www.airportsystems.honeywell.com
www.mpi-st.mpg.de	

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