Image processing performance analysis for low power wireless image sensors

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Outline

- Introduction
- Wireless Sensor Network for Videosurveillance
- Performance analysis of local image processing in the smart sensor node
  - Local image enhancement
  - Local image compression
- Conclusions

Wireless Sensor Network for VideoSurveillance

- Objective of the research work is the design of a Wireless Sensor Network for VideoSurveillance
- First goal is the design of a low power image sensor node
- This presentation addresses the performance analysis of local image processing in terms of
  - Image quality in presence of noise in the channel
  - Data rate requirements

Key aspects of smart image sensor node

- Low Cost, Low Power (Battery operated)
- Wireless for fast installation and easy use (ZigBee)
- Video Application (video surveillance)
  - High data rate on video streaming is necessary for high quality but this is incompatible with low power requirement
  - Low data rate is obtained with local image processing
- Local Processing:
  - Image enhancement, recognition, compression
  - Dynamic Power management of local processing
  - Wireless protocol and application layer for power reduction

Design challenges

All the following aspects of the complete sensor network must be analysed, designed and optimized in a system level simulation environment in order to optimize power consumption and quality of service.

- Algorithms of signal processing
- Architecture of the sensor node
- Wireless protocol from application layer to physical layer
- Network topology
- Power Management Techniques

Smart Wireless Image Sensor Node

Monitored place

Control Station

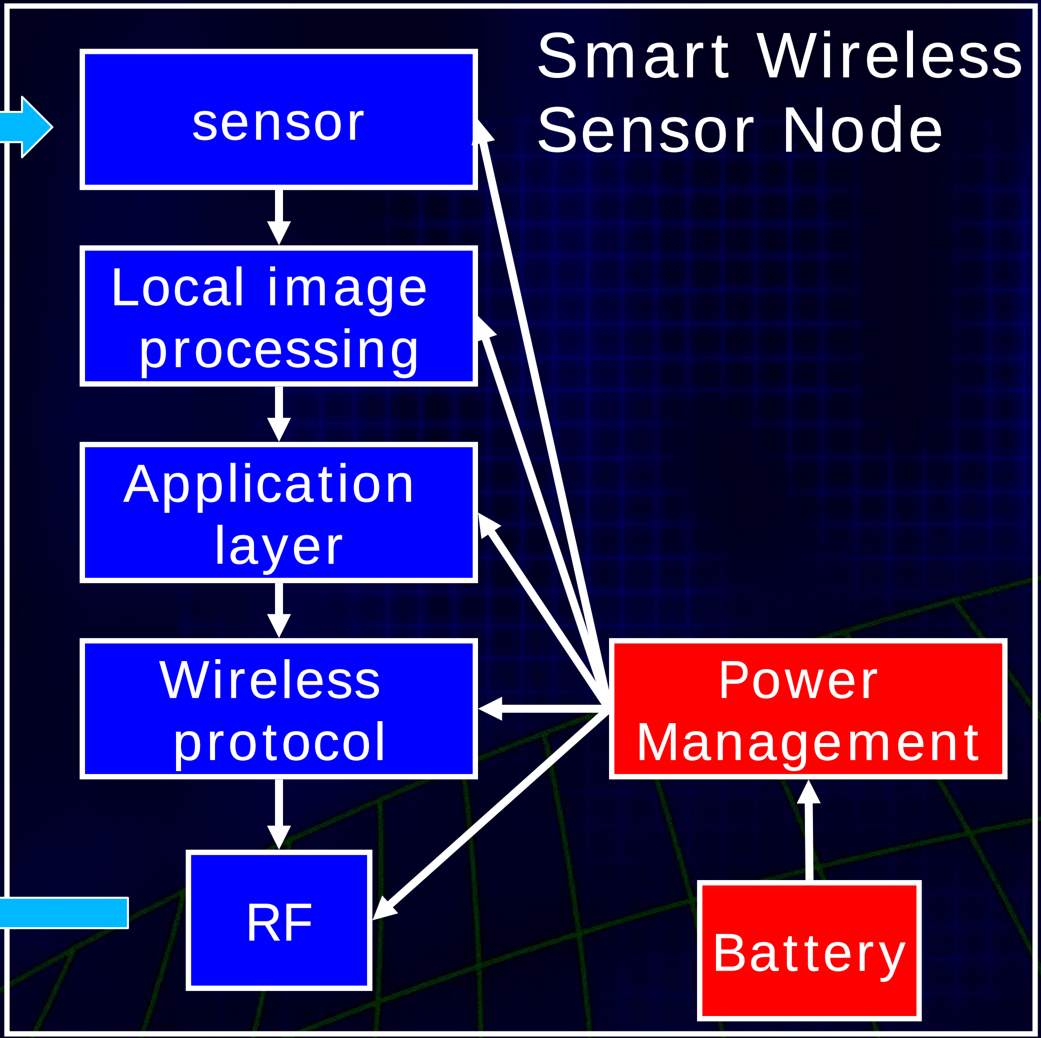
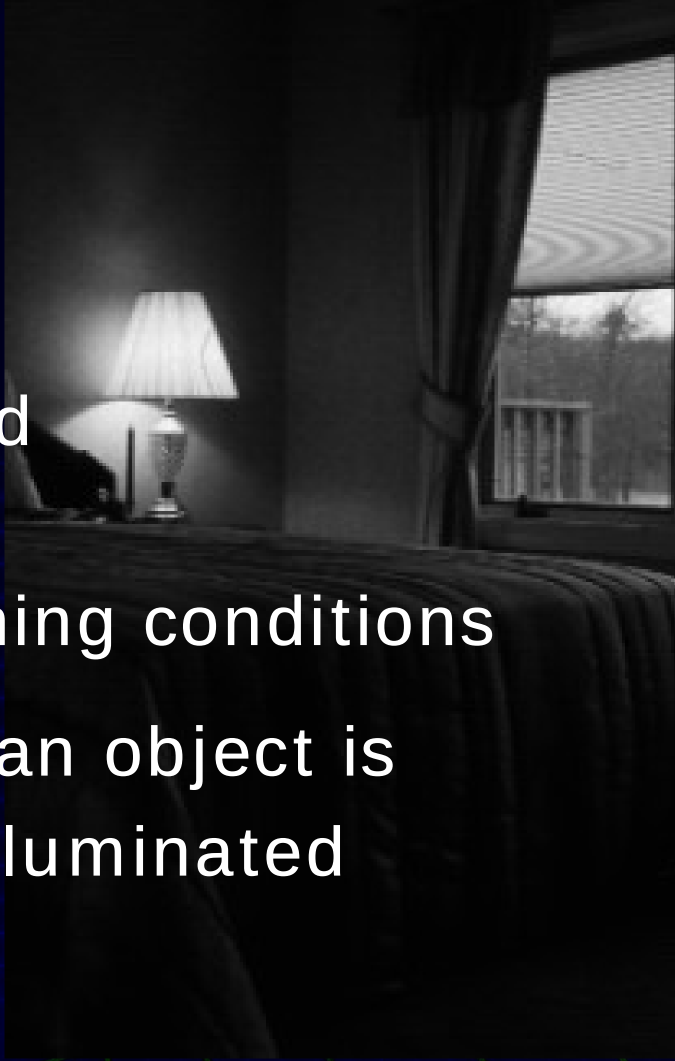
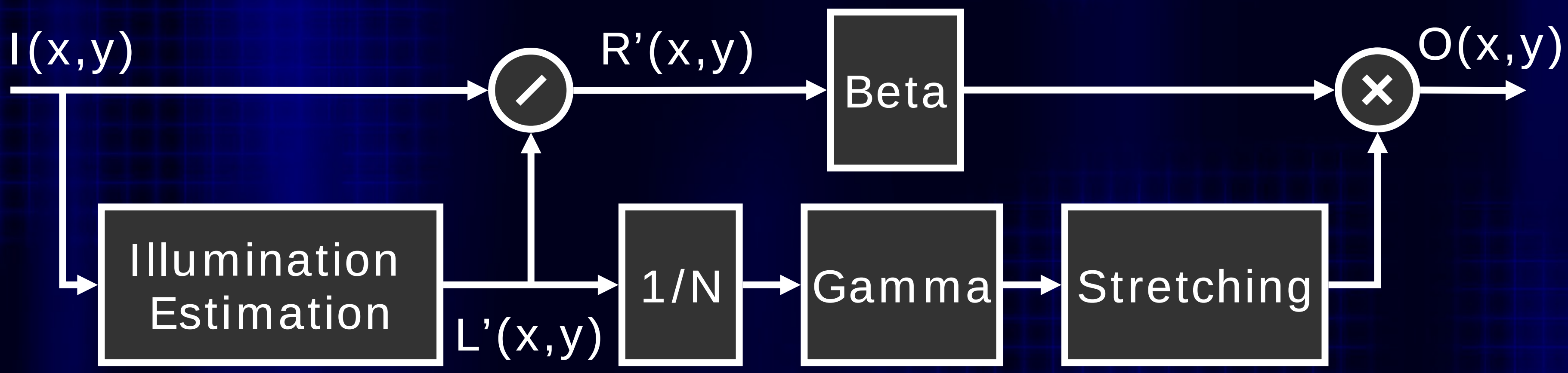


Image enhancement



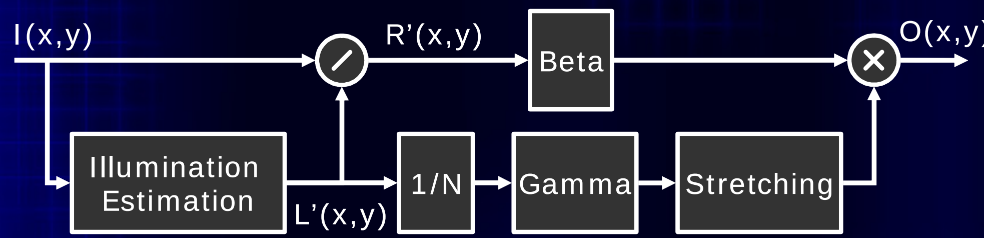
- Problem: improve the visual quality of digital images captured in critical conditions:
  insufficient or non uniform lightning conditions
- The human visual perception of an object is independent from the way it is illuminated thanks to adaptive mechanism (pupil size, retinal processing ...)
- Retinex Algorithm (Land 1971) improves the lightness in dark area and to emphasize the details using the illuminance-reflectance model

Retinex-Based Algorithms



- The *Illumination estimation* is essentially a low pass filter that estimates the illumination *L(x, y)* from the actual image *I(x, y)*;
- 1/N adapts the integer input range from [0:255] to [0:1];
- Gamma block enhances the global contrast of the image;
- Stretching maximizes the dynamics of the illumination;
- Beta block enhances the local contrast.

Retinex Hardware Complexity



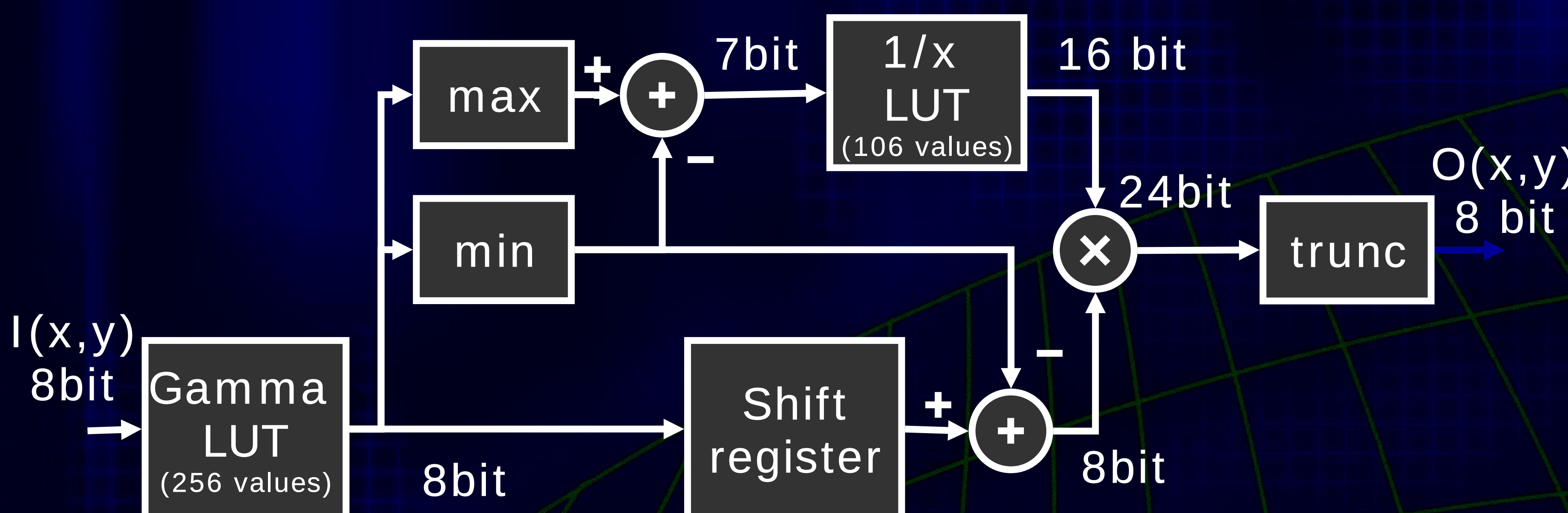
- The hardware implementation of the algorithm requires the implementation of complex functions of 32 bit fixed point numbers:
  - non linear bidimensional filters
  - exponential and logarithmic functions
  - multiplications, divisions
- A low cost low power implementation for real time applications is not possible

Necessity of strong simplification of the algorithm for a hardware complexity reduction

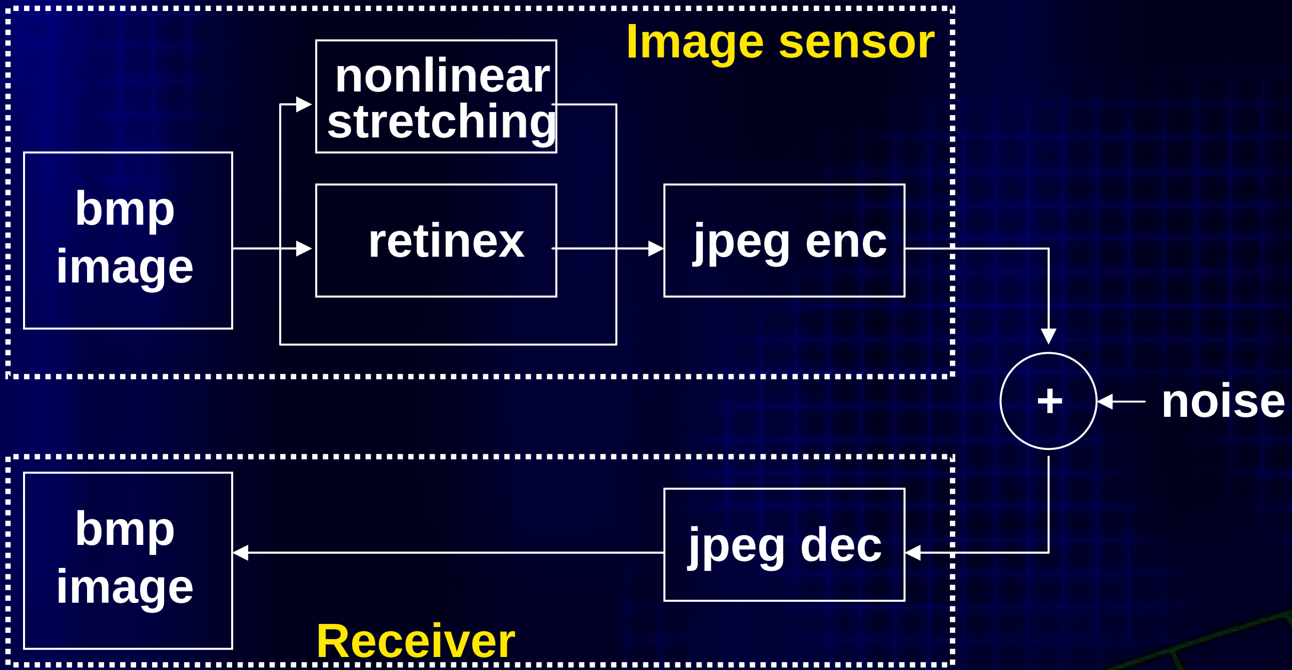
Simplified Algorithm: nonlinear stretching

$$Gamma(\tilde{L}) = 255\left(\tilde{L}/255\right)^{K\tilde{L}/255+K} \quad Streching(x,y) = 255\left(\frac{\text{Gamma(x,y)-min}}{\text{max}-\text{min}}\right)$$

Hardware Implementation



Signal processing flow in the node and in the receiver



- Analysis in matlab of image quality as a function of the jpeg compression factor for different values of noise in the channel and image enhancement algorithm

PSNR is the measure used for the quality of image processing

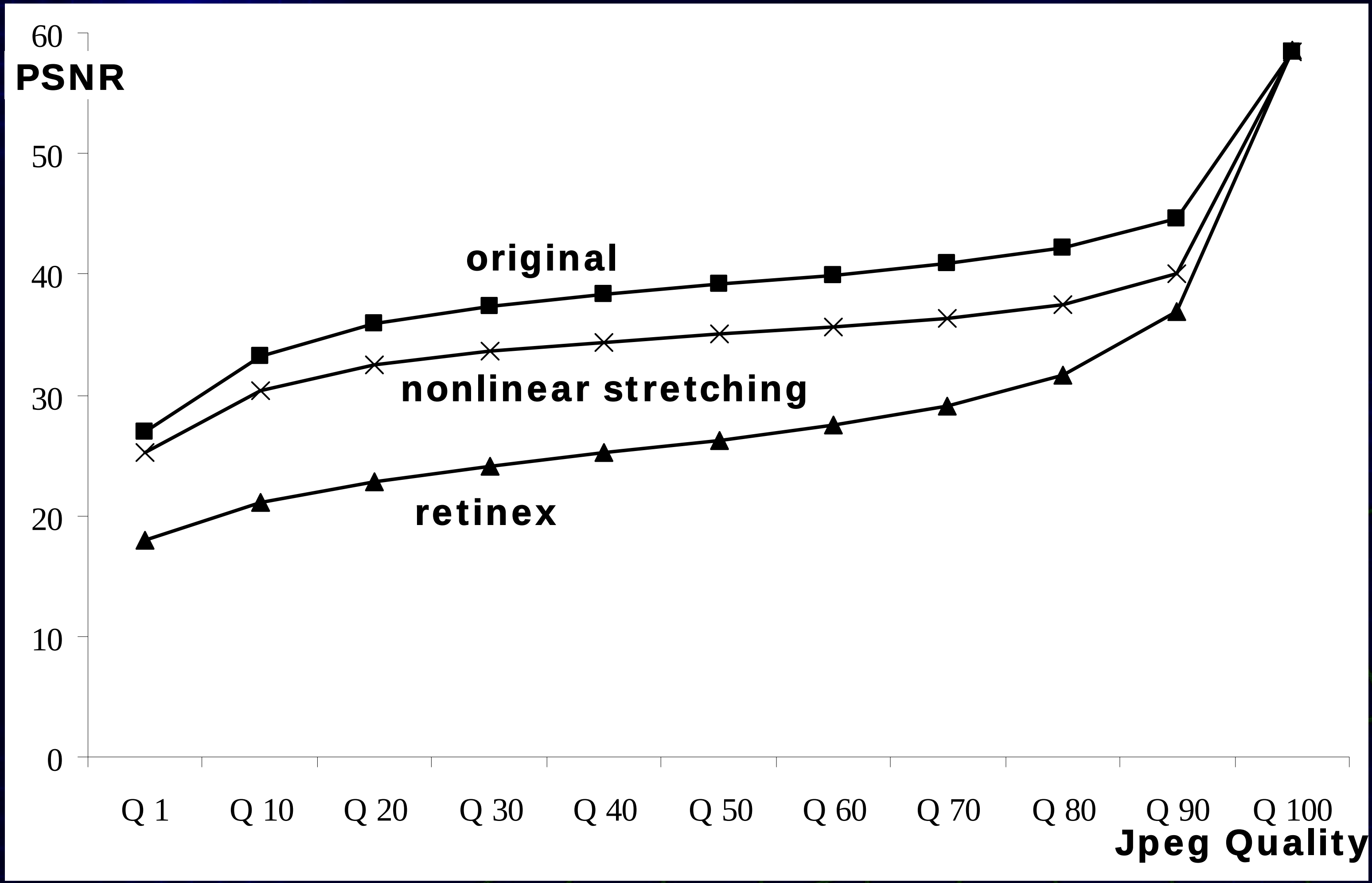
$$PSNR = 10\log_{10}\left[\frac{2^{2k}}{MSE}\right]$$

$$MSE = \frac{1}{n \cdot m}\sum_{i=1}^{n}\sum_{j=1}^{m}\left(I_1(i,j) - I_2(i,j)\right)^2$$

I1 and I2 are the to images to be compared

320x240 pixels, gray scale, 8 bit resolution

PSNR in dB for different values of the quality of jpeg compression and for the original, after nonlinear stretching or after retinex algorithms are applied



no compression

Original Image

PSNR: 35.9

jpeg compression quality 20%

no compression

PSNR: 22.8

jpeg compression quality 20%

Retinex

no compression

PSNR: 32.5

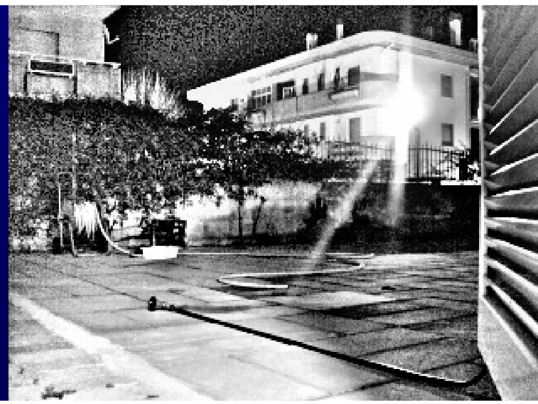
jpeg compression quality 20%

Nonlinear stretching

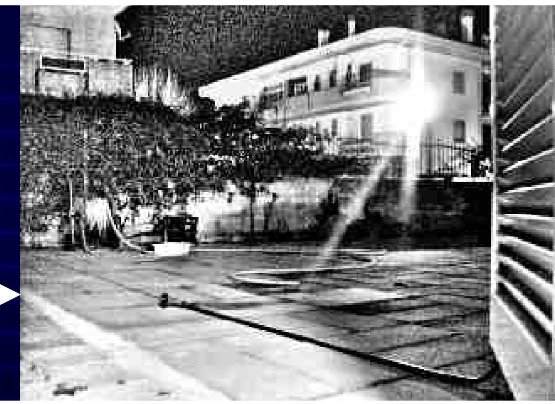
Original

PSNR 35.9

Retinex



PSNR 22.8

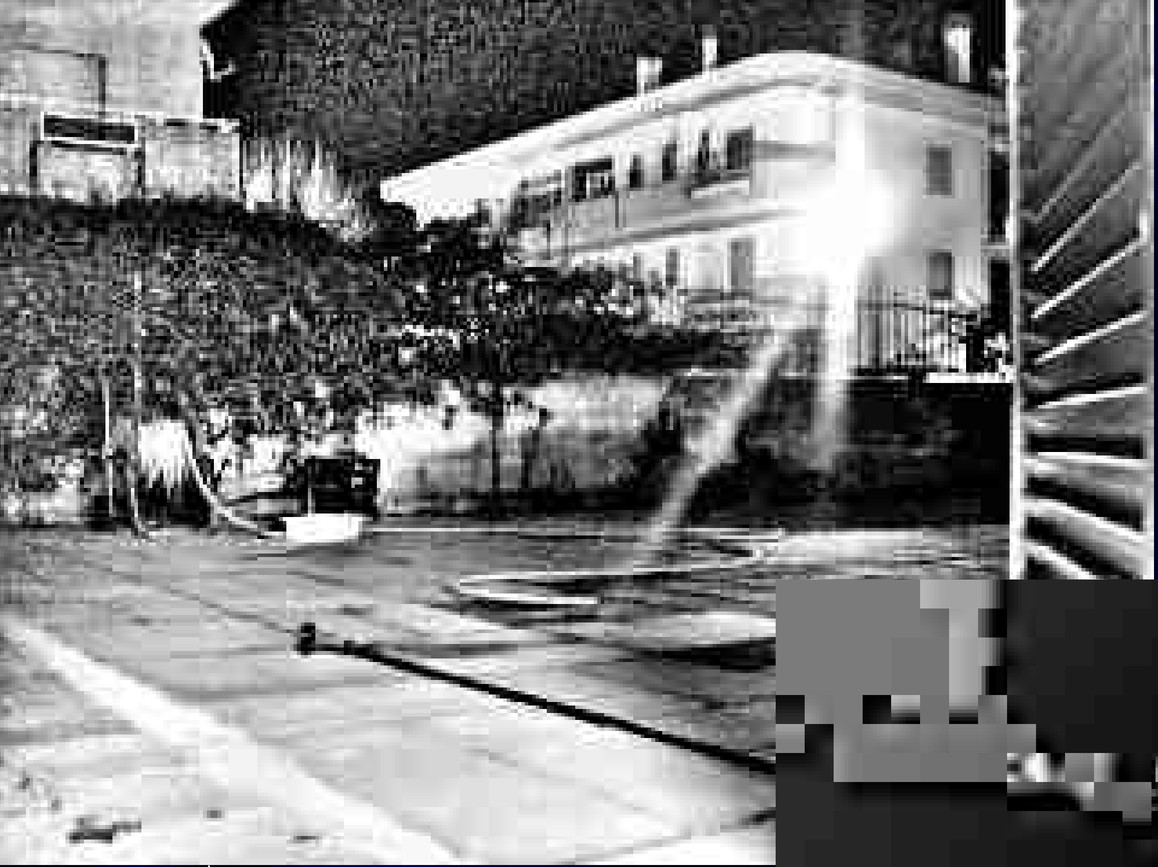


Nonlinear stretching

PSNR 32.5

no compression

jpeg compression quality 20%



Local compression
and retinex
in the control center

Local retinex
before compression

Local compression
and nonlinear
stretching
in the control center

Local nonlinear
stretching
before compression

Compression ratio with respect to the original bmp image (320x240, gray scale, 8 bit resolution, 76.800 bytes)

for different values of the quality of jpeg compression

for the original image and after nonlinear stretching or retinex algorithms are applied

compression ratio	Q1	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90	Q100
original	1,29%	1,94%	2,80%	3,61%	4,30%	5,01%	5,78%	7,01%	9,08%	14,10%	45,81%
nonlinear stretching	1,33%	2,52%	4,10%	5,57%	6,79%	8,08%	9,44%	11,54%	14,99%	23,71%	63,08%
retinex	3,24%	7,87%	12,71%	16,63%	19,94%	23,01%	26,26%	31,21%	38,32%	52,83%	109,61%

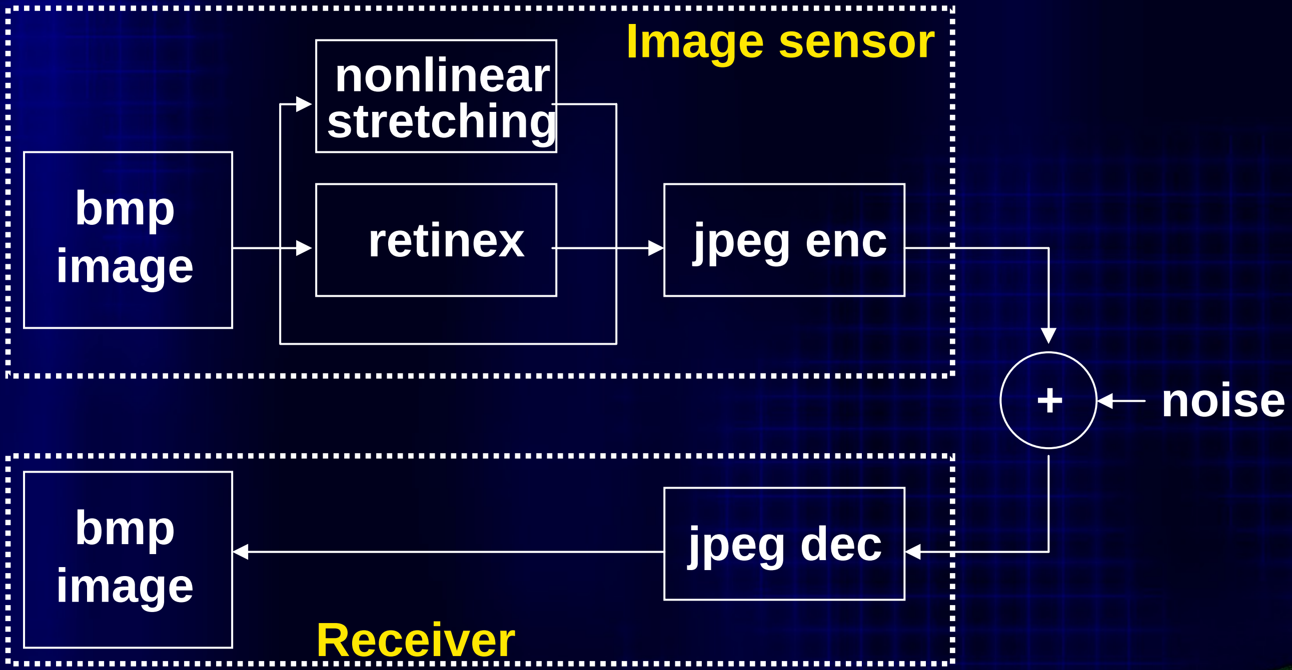
Image dimension after non linear stretching is 1/3 with respect to retinex:

Reduction in data to be transmitted

Comments

- Image compression must be performed in the sensor node to reduce data to be transmitted (3%)
- Image enhancement is essential to improve quality in bad illumination conditions
- Image enhancement must be performed before compression in the sensor node
- Compression ratio is higher for nonlinear stretching with respect to retinex

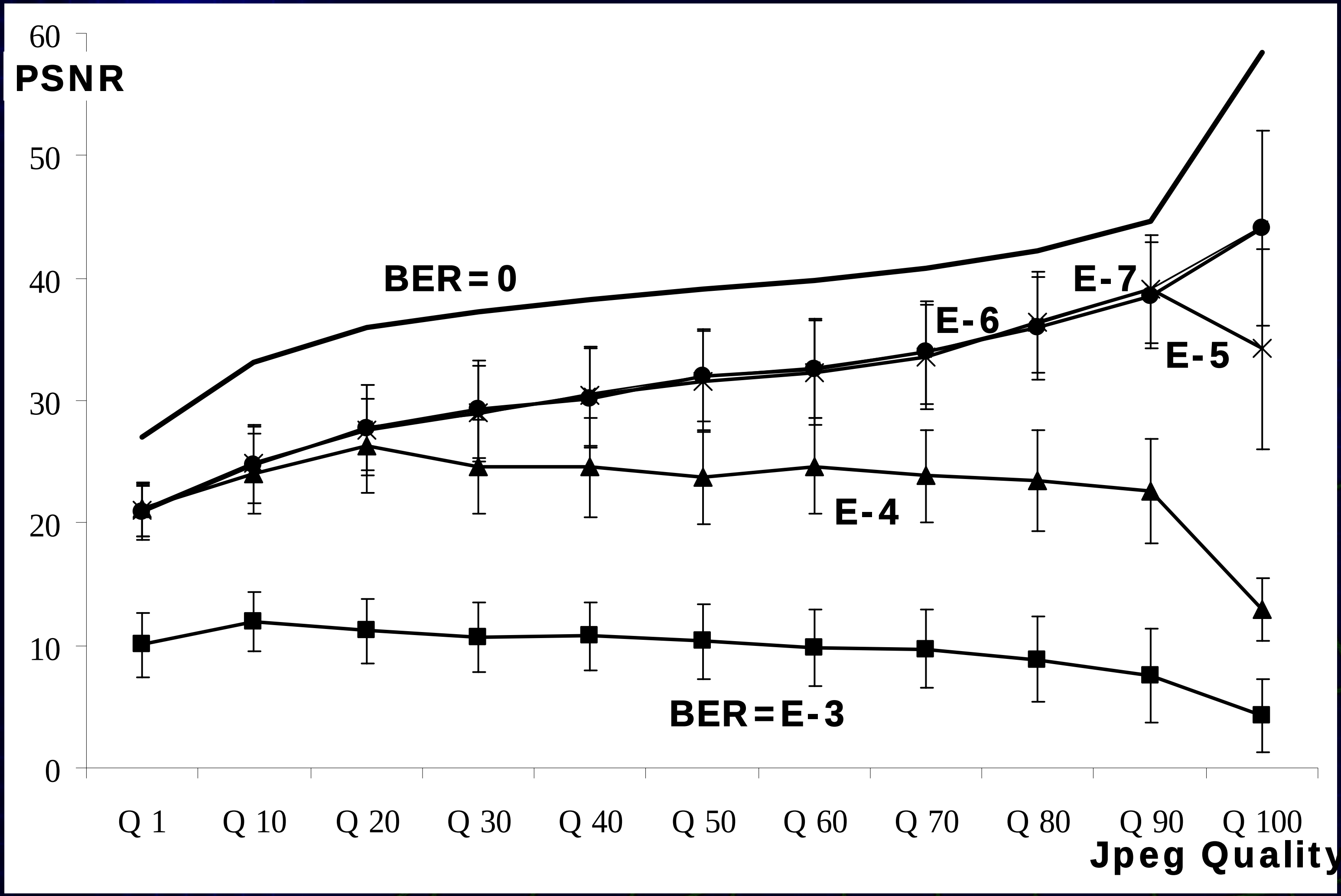
Image degradation due to the presence of noise in the channel

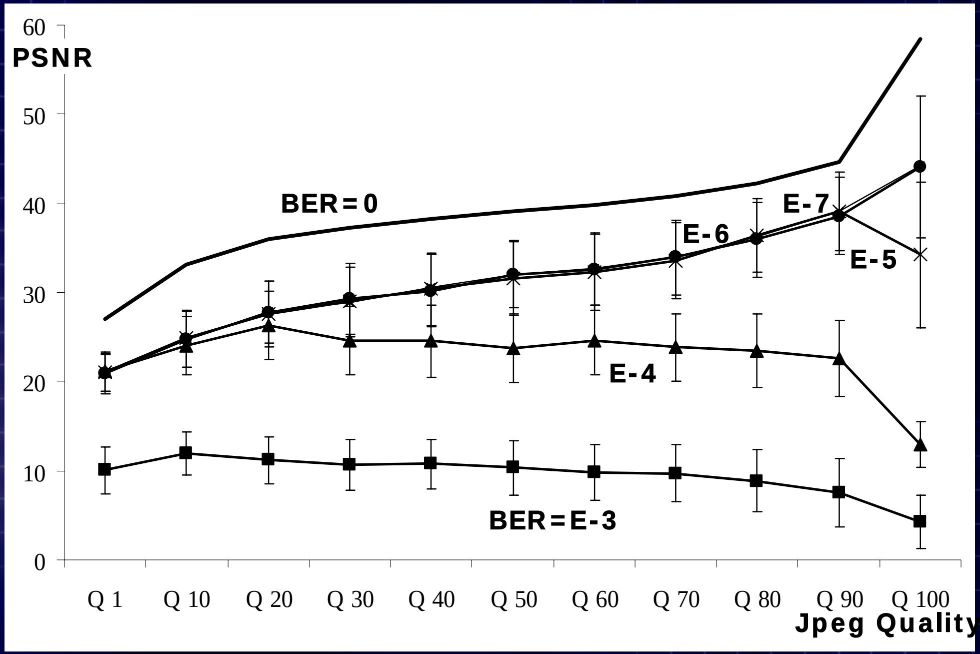


- matlab simulations
- random noise added with different BER
- results: average PSNR and std deviation calculated over 1000 simulations

PSNR in dB for different values of the quality of jpeg compression and for different values of BER in the channel

ORIGINAL IMAGE

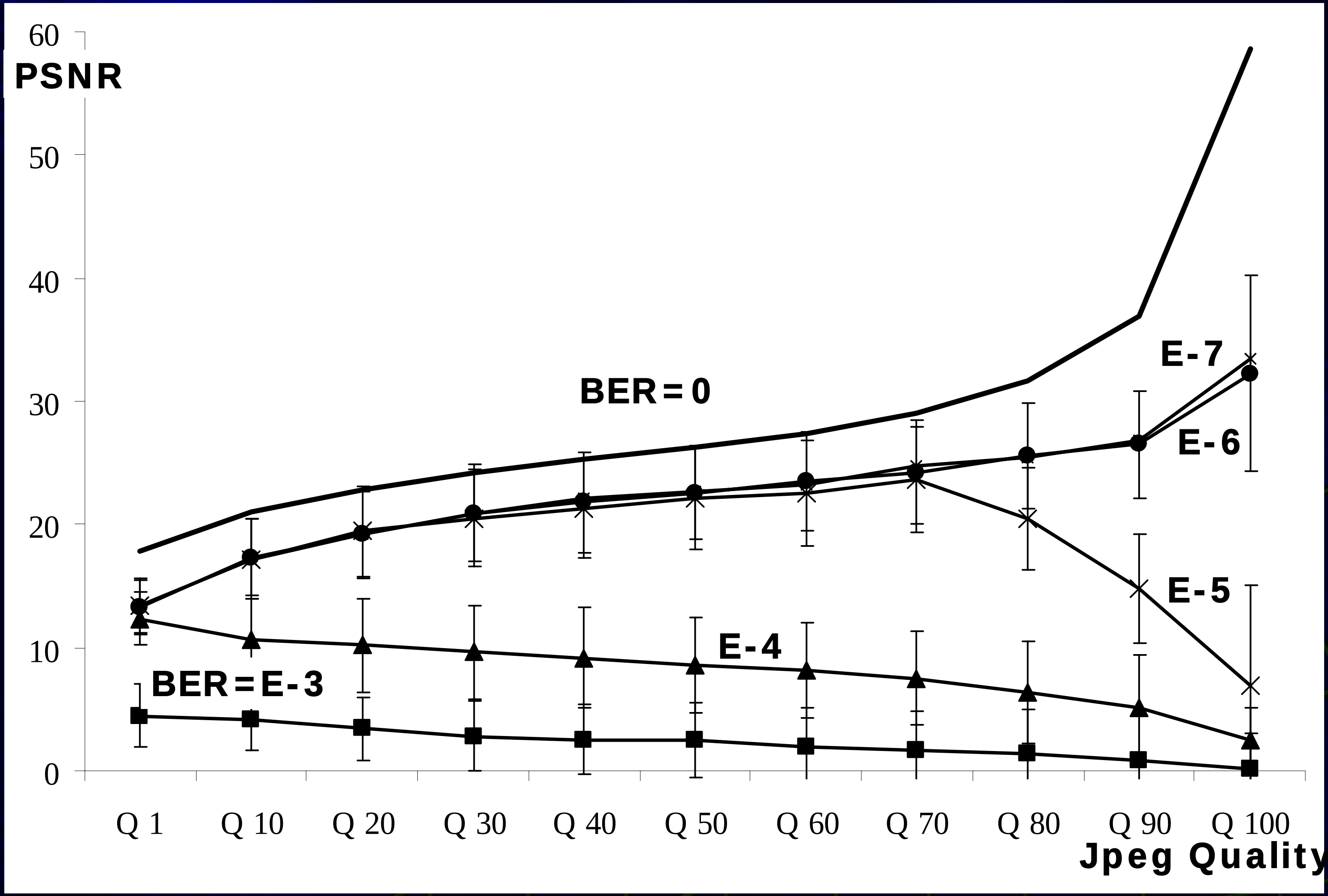




- Increasing the BER the PSNR reduces
- Increasing the jpeg quality, the image size increases the number of errors in the image increases, the PSNR increases
- Decreasing the jpeg quality, the effect of errors in the image on the PSNR increases
- Previous effects depend on the image enhancement algorithm applied

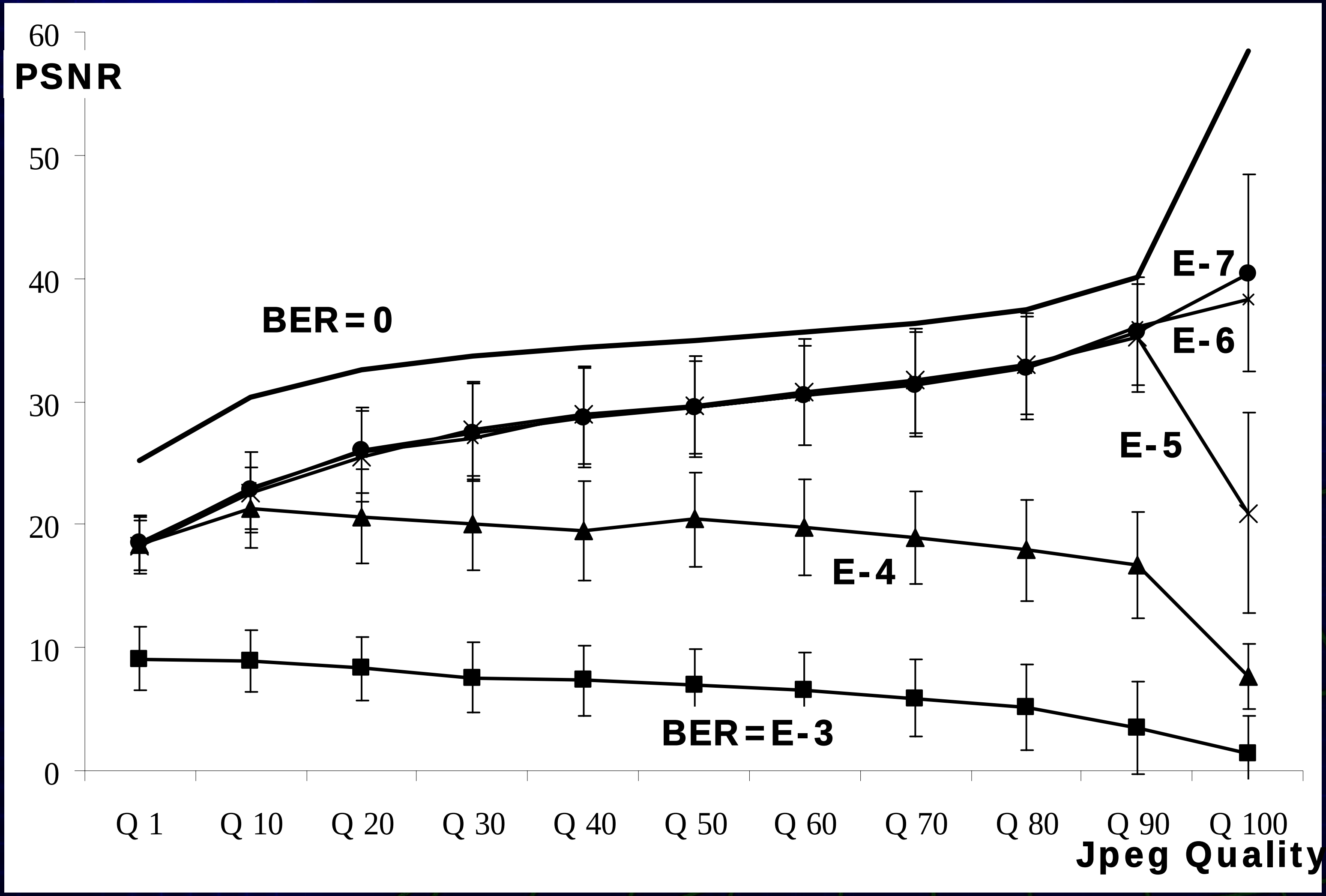
PSNR in dB for different values of the quality of jpeg compression and for different values of BER in the channel

RETINEX



PSNR in dB for different values of the quality of jpeg compression and for different values of BER in the channel

NONLINEAR STRETCHING



PSNR in dB
for different values of the quality of jpeg compression for different image enhancement algorithms (BER=E-4)

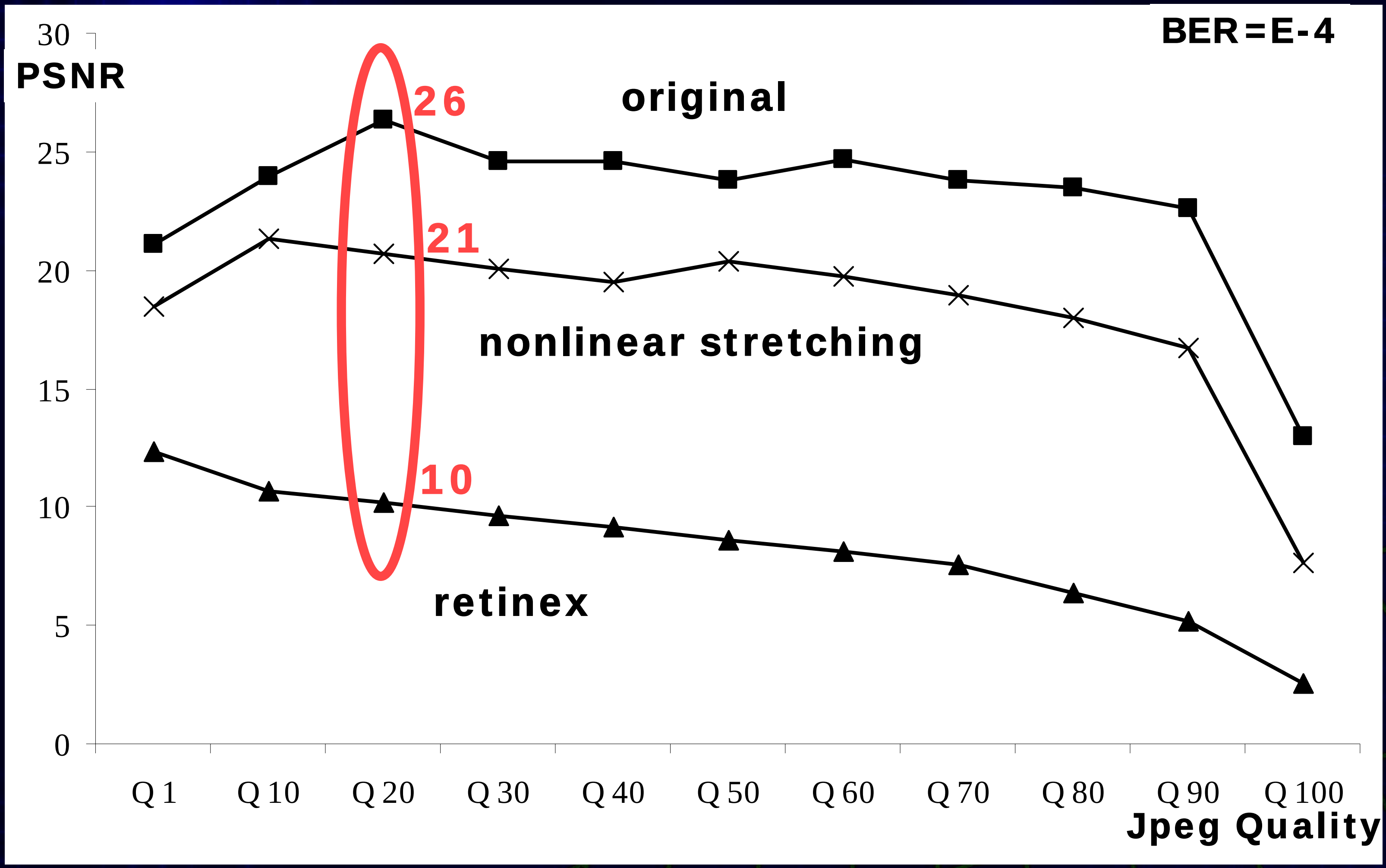


Image degradation due to noise more relevant for retinex with respect to nonlinear stretching

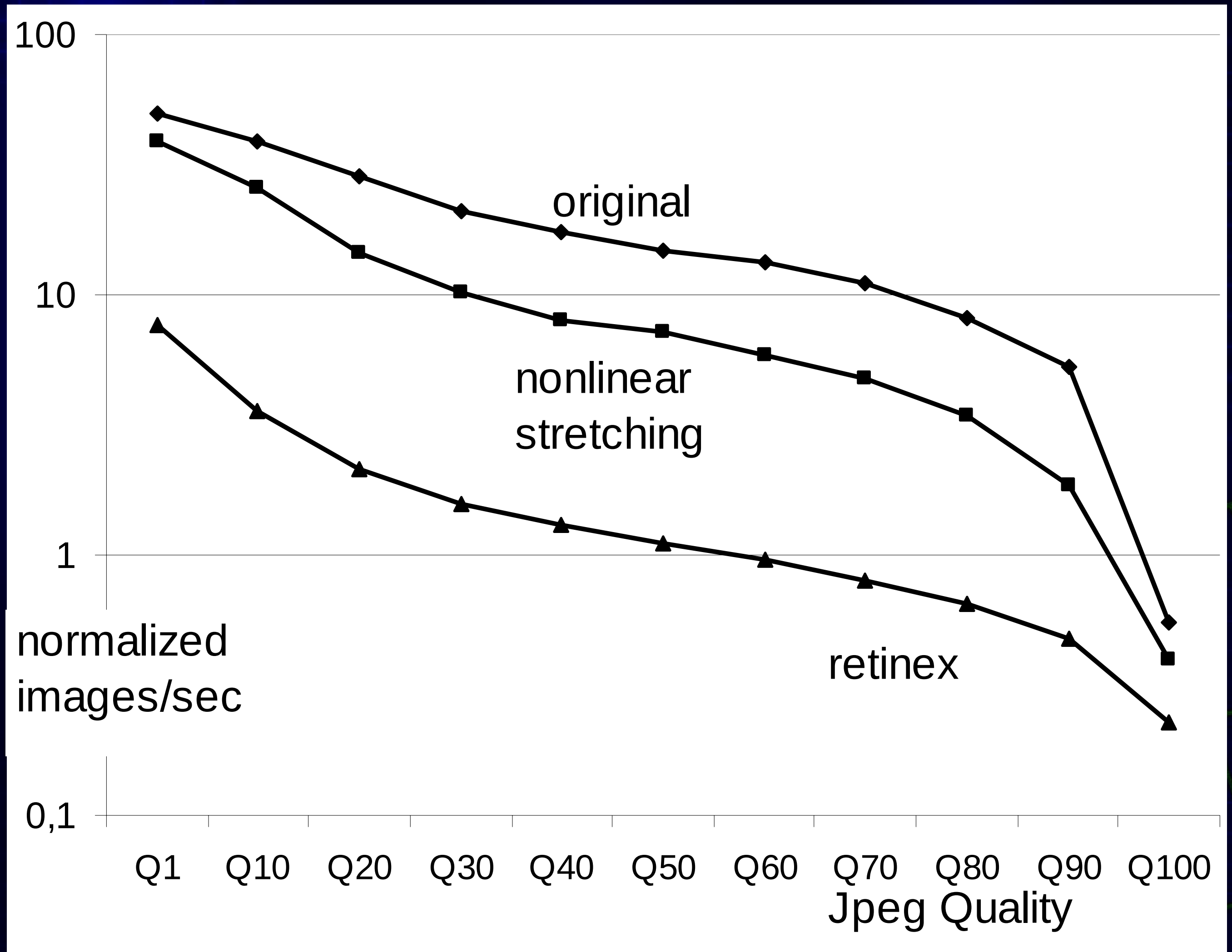
SystemC models of Bluetooth and 802.15.4 MAC

Simulation Results:

Effective throughput in kbps as a function of the number of sensors for the 802.15.4 and the Bluetooth

n. of nodes in the network	Bluetooth ACL Data Link DH1 packet type	802.15.04
1	163,20	125,29
2	81,60	67,06
3	54,40	46,31
4	40,80	36,04
5	32,64	29,31
6	27,20	24,70

Average number of images per second that can be transmitted over the ZigBee protocol in case of BER=1E-4 overcoming corrupted image with retransmission, normalized to the images/sec of the bmp image without noise (0.20 images/sec)



Maximum number of images per second that can be transmitted over the ZigBee protocol for different values of the quality of jpeg compression

maximum effective information rate 125kbps (1 transmitting node)

images/sec	Q1	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90	Q100	BMP
original	15.85	10.52	7.27	5.65	4.74	4.07	3.53	2.91	2.25	1.45	0.45	0.20
nonlinear stretching	15.38	8.09	4.97	3.66	3.00	2.52	2.16	1.77	1.36	0.86	0.32	0.20
retinex	6.30	2.59	1.60	1.23	1.02	0.89	0.78	0.65	0.53	0.39	0.19	0.20

maximum effective information rate 26kbps (5 transmitting nodes)

images/sec	Q1	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90	Q100	BMP
original	3.16	2.10	1.45	1.13	0.95	0.81	0.70	0.58	0.45	0.29	0.09	0.04
nonlinear stretching	3.07	1.61	0.99	0.73	0.60	0.50	0.43	0.35	0.27	0.17	0.06	0.04
retinex	1.26	0.52	0.32	0.24	0.20	0.18	0.15	0.13	0.11	0.08	0.04	0.04

Ongoing Hardware Implementations

Hardware Implementation on commercial demo board (in cooperation with Freescale and Micron)

Micron Smart Camera demo board

Freescale ZigBee demo board

Conclusions

- Analysis in matlab of image quality as a function of the jpeg compression factor for different values of noise in the channel and image enhancement algorithm
- Image enhancement is essential to improve quality in bad illumination conditions
- Nonlinear stretching allows better performances with respect to retinex in terms of:
  - Image quality with or without noise
  - Data rate
  - Hardware complexity