Digital Image Processing

11 January 2007

Dr. ir. Aleksandra Pizurica
Prof. Dr. Ir. Wilfried Philips

Aleksandra.Pizurica @telin.UGent.be
Tel: 09/264.3415

UNIVERSITEIT
GENT
Telecommunicatie en
Informatieverwerking

INSTITUUT VOOR
PERMANENTE
VORMING

Video Denoising

Applications of video denoising

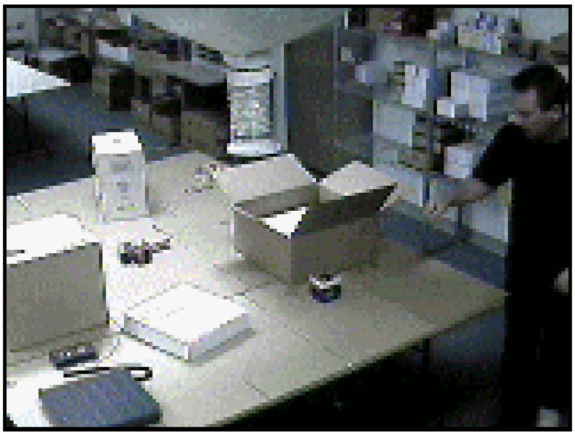
Video denoising is important in numerous applications, including

television

surveilance
(security, traffic surveillance,..)

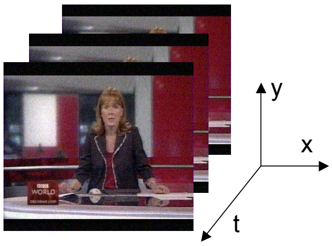

- Video-conf.
- Restoration of old movies
- Medical video
- …

An example: indoor surveillance



Noise is especially pronounced in low-light conditions, like indoor surveillance and in night vision

Introduction to video processing



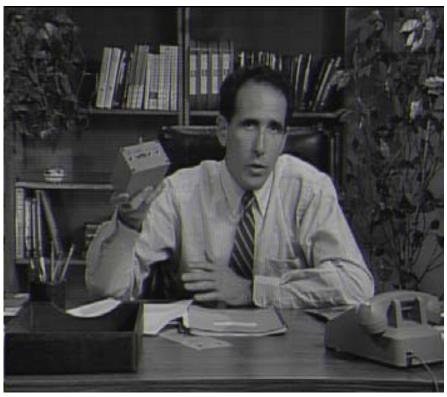
Video can be described as 3-dimensional data

There is a great spatial and temporal redundancy in video

- In static areas noise is removed best by temporal filtering (no spatial bluring occurs)
- A key of any successful video processing method is motion detection and/or motion estimation
- Most often real-time processing is required and hence the algorithms need to be of low-complexity and/or hardware-friendly
- In some applications (e.g., restoration of old movies) the processing is off-line and the involved algorithms can be more complex

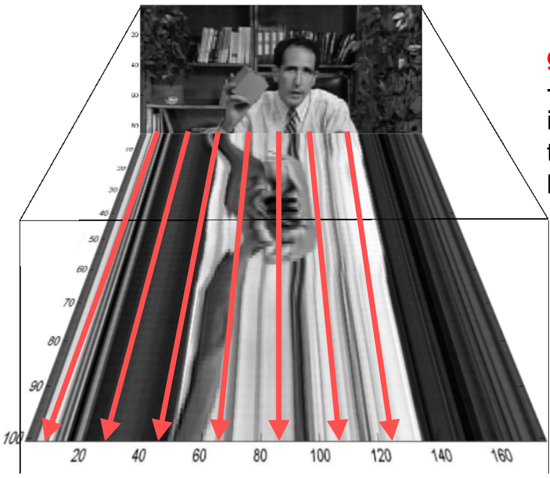
Example test sequence

“salesman”



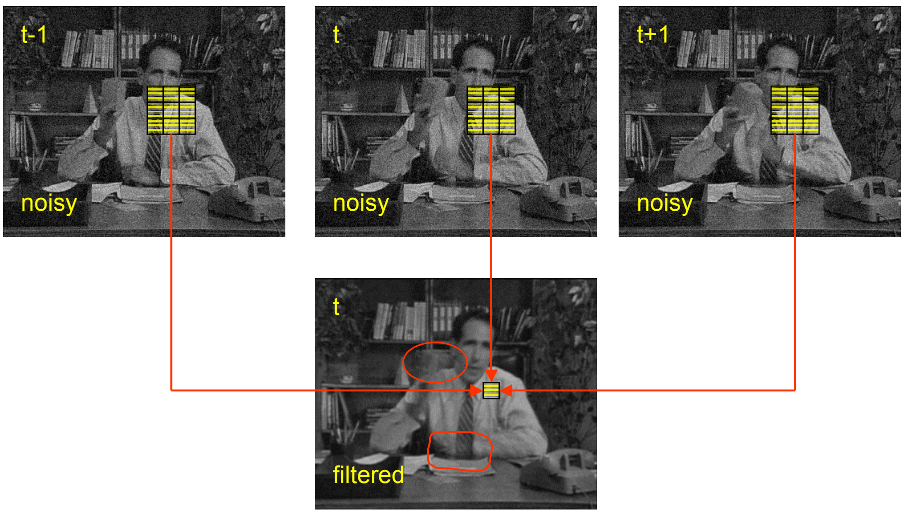
Static background, no zooming

Temporal filtering

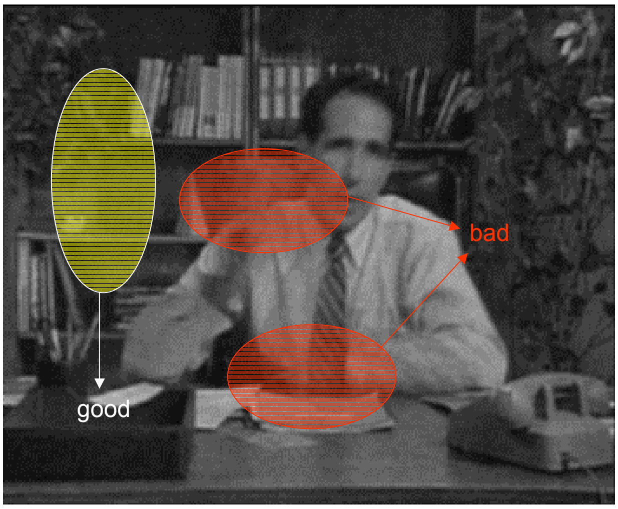


Probleem: in moving areas ghost artefacts -
- structures that are not present in the current frame appear or the actual structures dissapear being filtered out

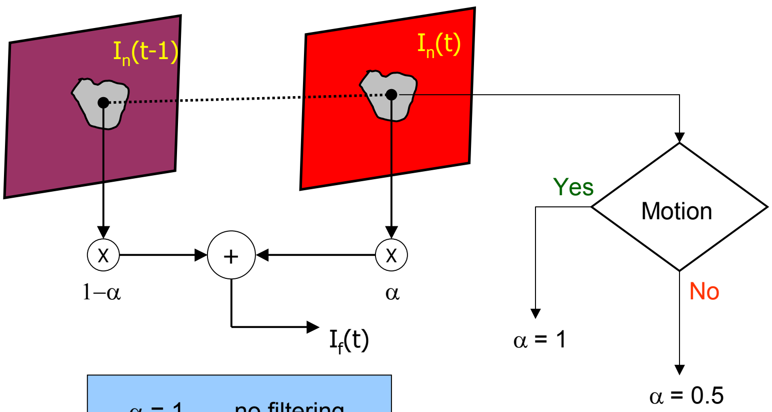
Motion blur due to temporal filtering



Motion blur due to temporal filtering

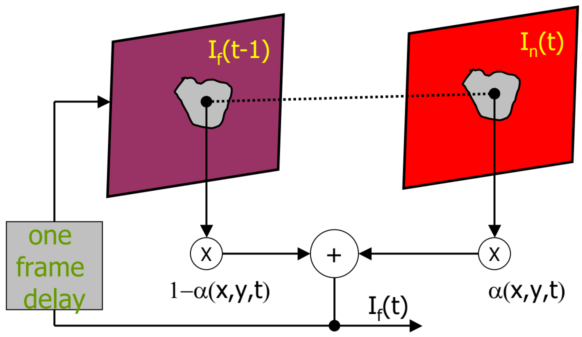


Motion adaptive temporal averaging



α = 1 -- no filtering
α = 0.5 -- averaging

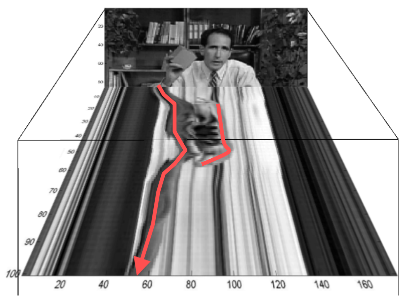
Recursive motion adaptive filtering



α – is increasing function of motion label Θ

lower α values result in stronger filtering !

Filtering along the motion trajectory



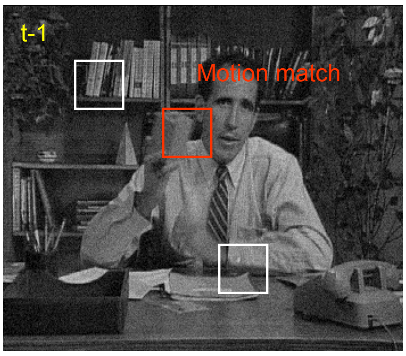
Advanced temporal filters for video filter along the estimated motion trajectory – this is called motion compensated filtering

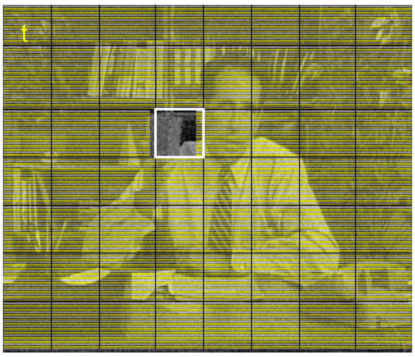
Problem: motion estimation is never perfect!

A possible solution: estimate the reliability of the motion estimates and filter more where reliability of the motion estimates is higher

Even advanced, temporal filtering alone is in general not sufficient for a superior quality. Spatio-temporal (“3-D” filtering) yelds best performance

Motion estimation: block matching

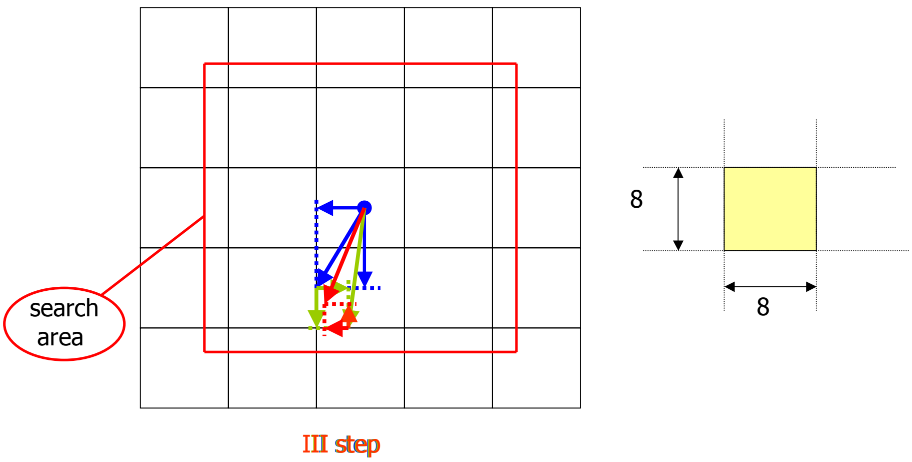




$$MAD_W^{(l)} = \frac{1}{N_x N_y} \sum_s |W(s,t) - W(s - \mathbf{v}, t-1)|$$

version: 11/1/2007
© V. Zlokolica, 2006

Motion estimation: block matching



Reliability of motion estimation

In uniform regions (green squares) motion cannot be accurately estimated

Along edges (yellow boxes) motion reliability is also low, unless motion is perpendicular to the edge

Reliability of motion estimates is highest for blocks that contain corners (blue squares)

Basic video filtering strategies

Non-separable 3D approach – process a 3D box of the data simultaneously

Separable spatial+temporal approaches

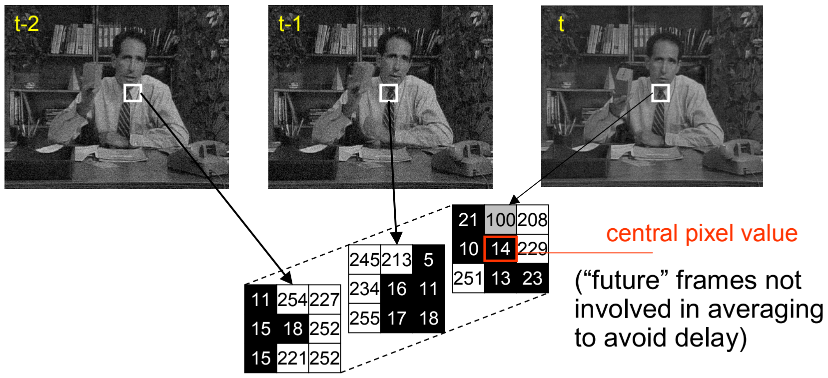
- sequential
  - spatial → temporal
  - temporal → spatial
- combine separate spatial and temporal filtering

Separable approaches often employ time-recursive filtering. This type of filtering requires less memory (one frame buffer) and no frame delay

Drawbacks: many possibilities to combine, no unique solution

Non-separable 3D solutions – less ambiguities – elegant formulation. Drawbacks: memory, frame delay, do not take into account that the difference in temporal and spatial resolution

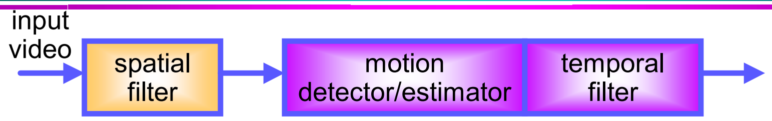
Non-separable filters: 3D KNN



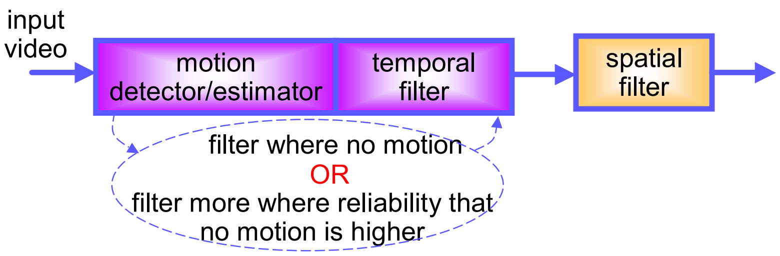
KNN – K nearest neighbours – average K pixel values from a 3D window that are nearest in value to the central pixel

Similar concept: "threshold averaging" proposed by V. Zlokolica – average those pixel values from a 3D window that differ from the central pixel value less than a given threshold

Separable filtering: sequential approach…



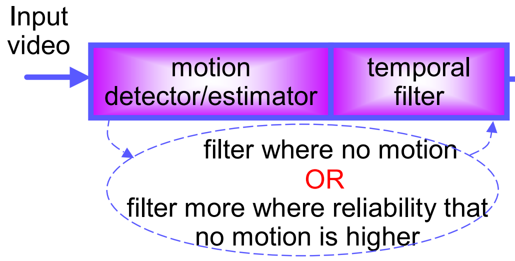
+ motion det./est. can be quite simple because noise is suppressed
- spatial blurring is introduced even at static places (where it could have been avoided by using temporal filter only)



+ less spatial blurring
- spatial filtering more difficult – deals with non-stationary noise
- motion estimation/detection more difficult due to input noise

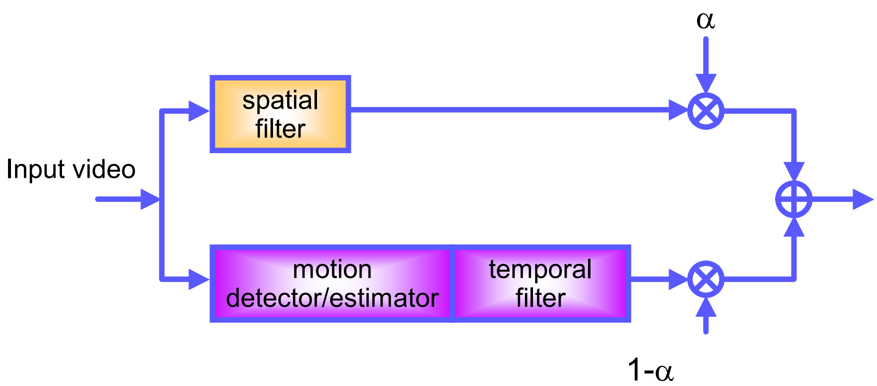
Separable filtering: sequential approach…

More noise remains in the moving areas



+ less spatial blurring
- spatial filtering more difficult – deals with non-stationary noise
- motion estimation/detection more difficult due to input noise

Separable filtering: sequential approach…

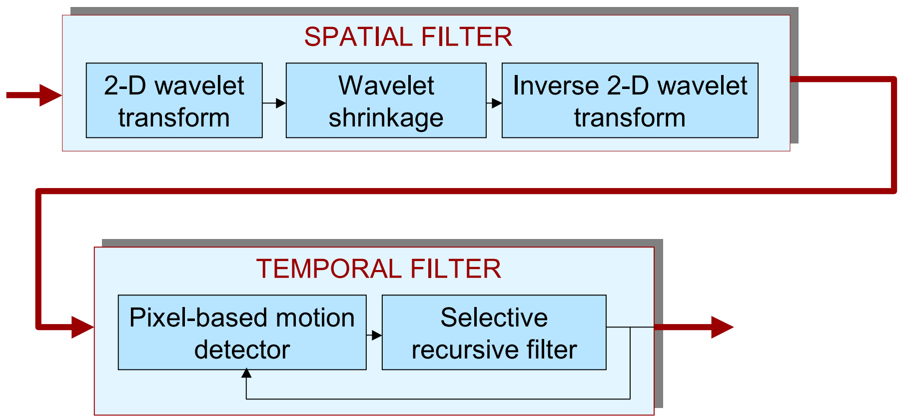


$0<\alpha<1$ and α should be bigger where motion is bigger and/or where reliability to the estimated motion is smaller

+ potentially most powerful
- How to combine the outputs of the spatial and the temporal filter ? (multiple chices for weighting factors)

Wavelet domain video Denoising

SEQWT filter

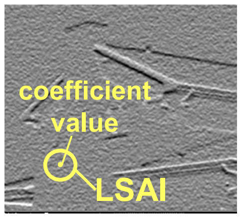


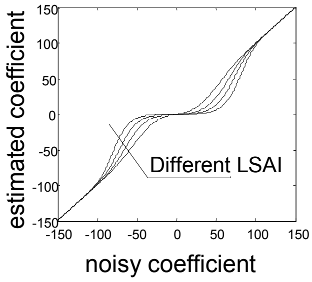
Sequential wavelet domain and temporal filtering (Pizurica et al., 2003)

SEQWT filter: spatial filtering part

- Define **signal of interest** as *noise-free* coefficient component exceeding noise standard deviation

- Estimate the **probability** that a coefficient presents a signal of interest based on
  - **Coefficient value**
  - **Local spatial activity indicator** (**LSAI**) locally averaged magnitude
  - **Global statistical distribution** of the coefficients in a given subband





SEQWT filter: temporal filtering part

Selective recursive time filtering of spatially filtered frames

Step 1: **pixel based motion detection**

from $f_l^{2D,k}$ – pixel l in $2D$ filtered frame k

to $f_l^{3D,k-1}$ – pixel l in $3D$ filtered frame k-1

$$m_l^k = \begin{cases} 0, & \text{if } |f_l^{2D,k} - f_l^{3D,k-1}| < T \\ 1, & \text{otherwise} \end{cases}$$

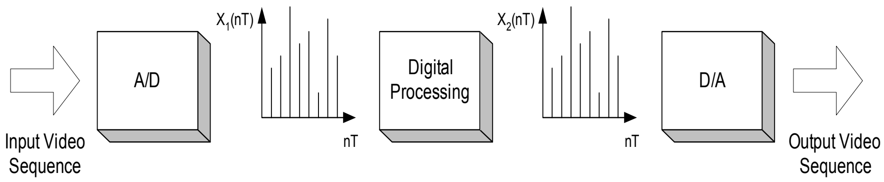
Step 2: **motion -> no change**. **No motion -> weighted average**

$$f_l^{3D,k} = m_l^k f_l^{2D,k} + (1-m_l^k)[a\, f_l^{2D,k} + (1-a)\, f_l^{3D,k-1}]$$

Real-time environment

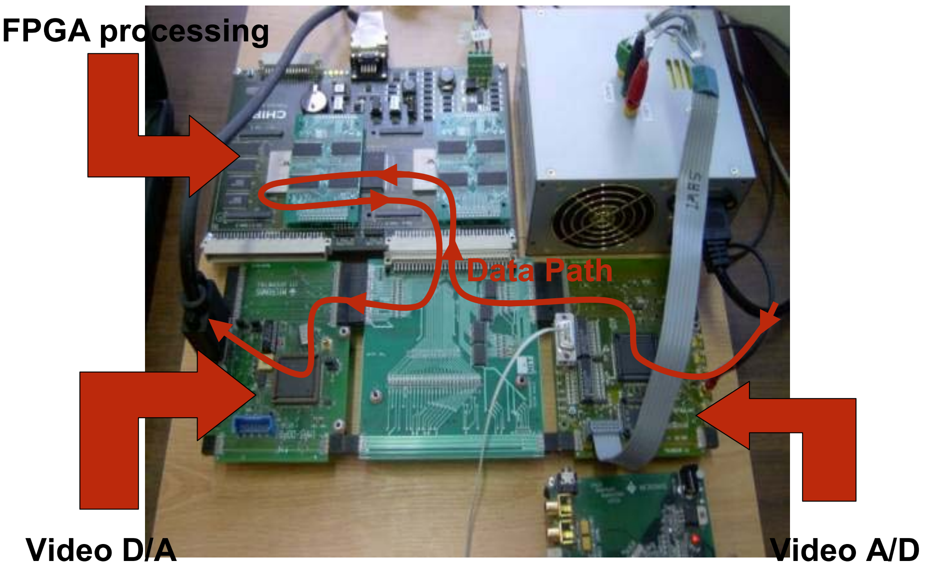
TV broadcasting sequence

Digital processing block implemented in
Field Programmable Gate Arrays (FPGA)

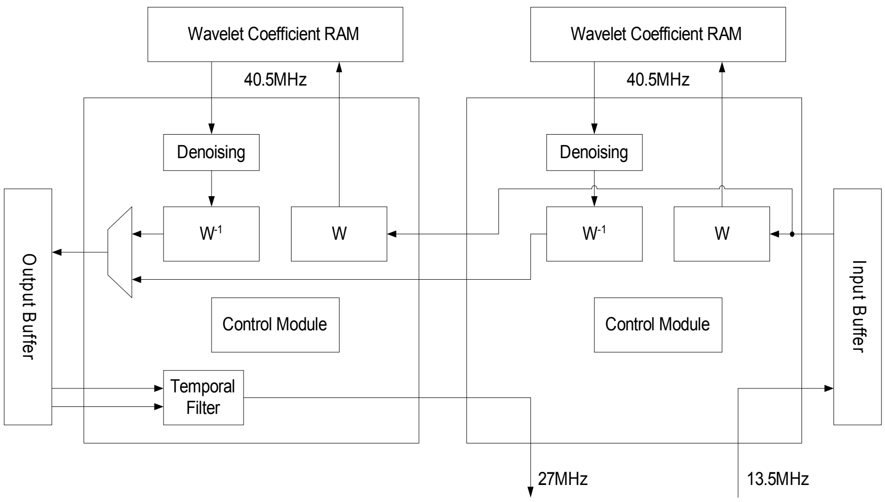


© A. Pizurica, Universiteit Gent, 2007

SEQWT filter: hardware platform

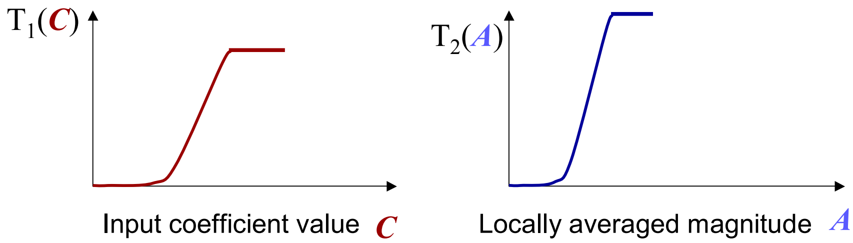


SEQWT filter: video sequence data path



SEQWT filter: implementation details

Two look-up tables are used:



$$C_{out} = \frac{T_1(C)T_2(A)}{1 + T_1(C)T_2(A)} C$$

Hardware platform setup

Processing boards

- **FPGA board**: CHIPit Professional
  (Two Xilinx Virtex II FPGAs, 6mil gates each)
- **Video A/D board**: VPC board
- **Video D/A board**: DDPB board

System interfaces

- **Video input:**
  CVBS; 50Hz scan rate
- **Video output:**
  RGB/Interlaced/PAL-B; 100Hz scan rate

Some other implementation details

Currently: fixed denoising levels

- Noise standard deviations: 5, 10, 20, 30

Integer arithmetic (16 bit)

Pipelined video processing

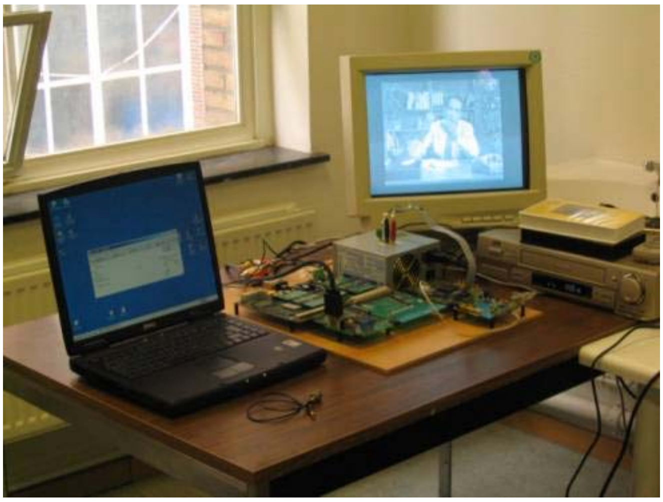
(paralelized operations and data distributed in pipelined structure)

Synthesis results

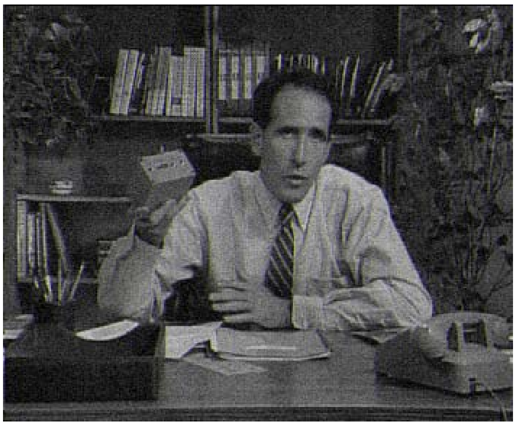
• Number of occupied Slices:	9,131	out of	33,792	27%
• Number of MULT18X18s:	57	out of	144	39%
• Number of Block RAM:	112	out of	144	77%

- Design with 4 clock domains (13.5; 27; 40.5 & 108MHz)

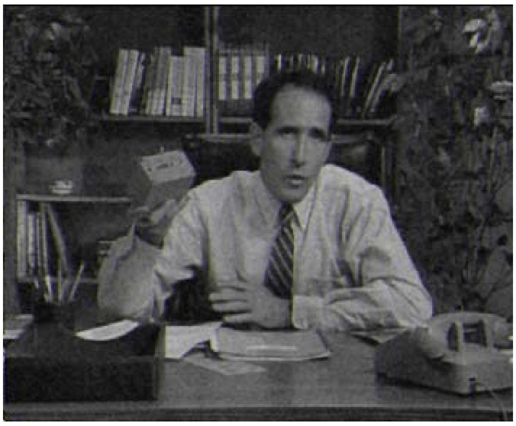
Hardware demonstrator



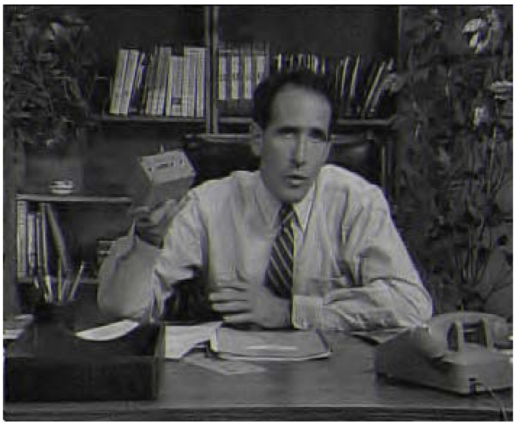
Noisy sequence



Single resolution 3D rational filter



SEQWT filter



Noisy flower sequence

Single resolution 3D rational filter

Single resolution 3D KNN filter

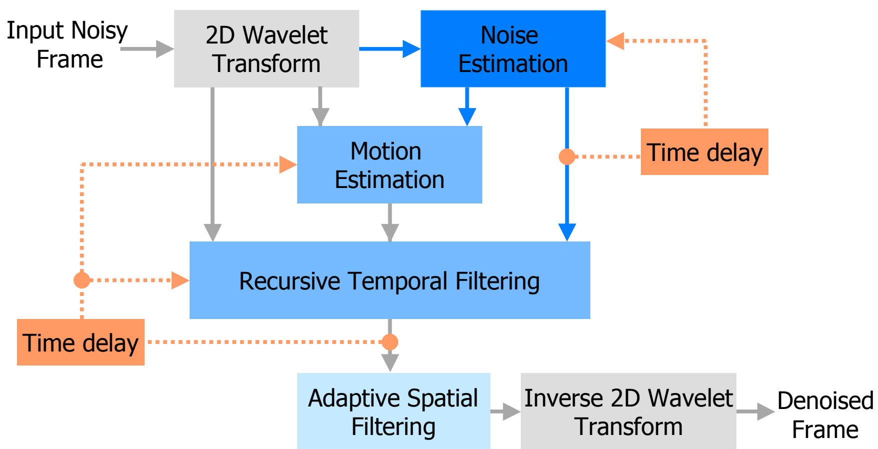
SEQWT filter

Advanced filters:
motion compensated wavelet domain video denoising

Some parts based on Ph. D. thesis of V. Zlokolica and engineering thesis of Bart Goossens

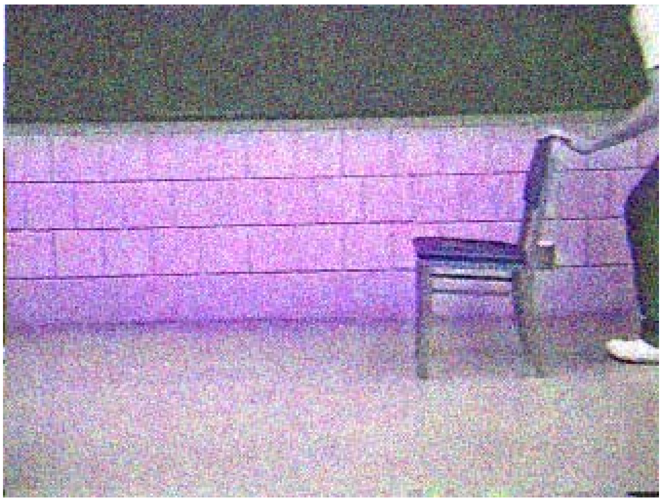
Ghent University

Motion compensated wavelet domain denoising



Developed by V. Zlokolica, Ghent University

Motion field: direction of motion vectors

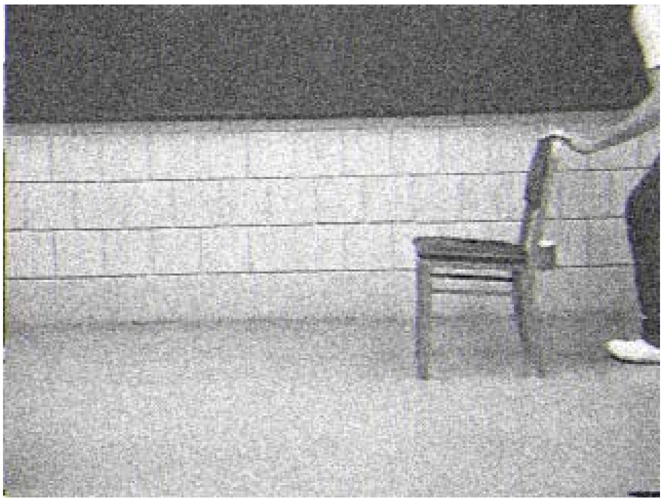


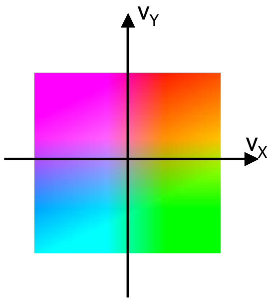
center of
the motion block

motion direction
(smaller amplitude)

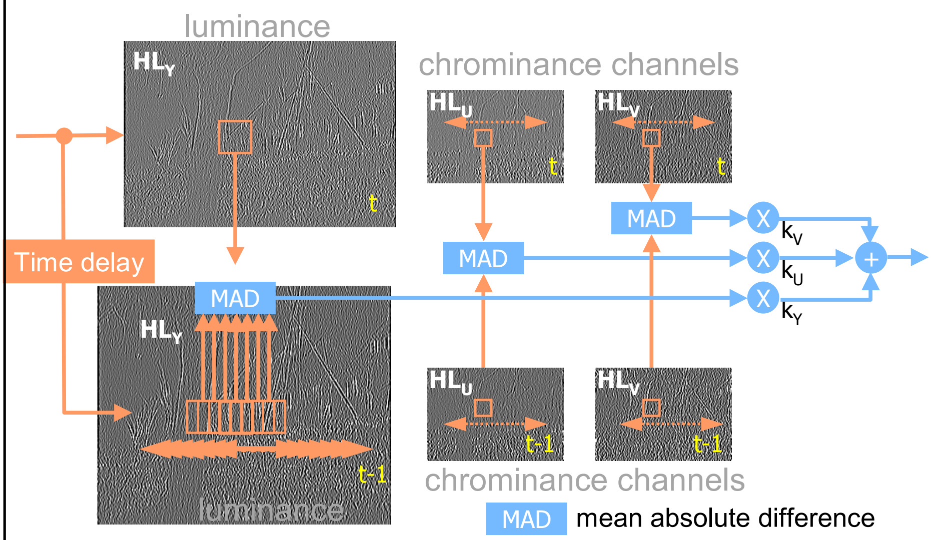
motion direction
(larger amplitude)

Consistency of neighboring motion vectors

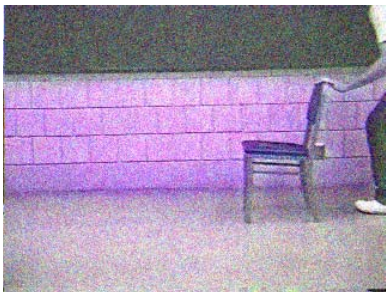


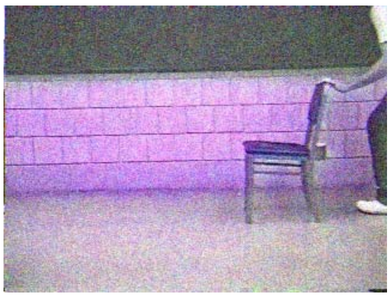


Wavelet domain block matching



Motion compensated denoising: example 1



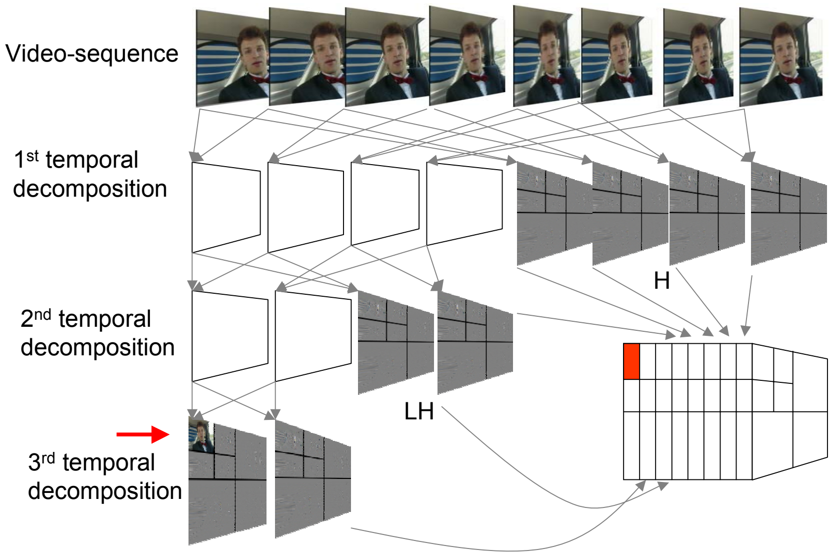


Motion compensated denoising: example 2

Motion compensated denoising: example 3

Motion compensated 3D wavelet lifting

B. Goossens, master thesis, Ghent University



version: 11/1/2007
© A. Pizurica, Universiteit Gent, 2007

Motion compensated 3D wavelet lifting

Some challanges:

Ghost artefact reduction

Scene change detection