Emilio Andreozzi

Tutor: Mario Cesarelli – co-Tutor: Paolo Bifulco

XXXIII Cycle - II year presentation

Improvements of noise suppression for low-dose X-ray imaging

CONTEXT

Fluoroscopy is an **X-ray** medical imaging modality, which provides a **continuous real-time screening** of body parts and various surgical instruments. Therefore, it is an invaluable tool for **interventional radiology** and also for several diagnostic and therapeutic procedures.

The European Directive 2013/59/Euratom emphasizes the need to **minimize** the patients' **exposure** to X-ray radiations, thus **low-dose X-ray** imaging procedures are becoming increasingly popular.

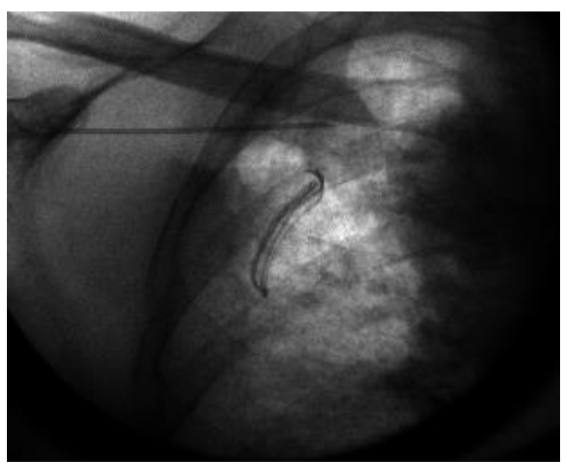
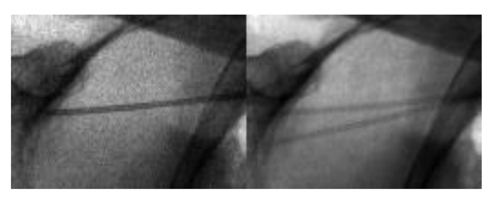


Image quality decreases with lowering the dose, due to the emergence of Poisson noise, also known as "**quantum noise**", so a **real-time image processing** algorithm for noise reduction is needed.

TRENDS

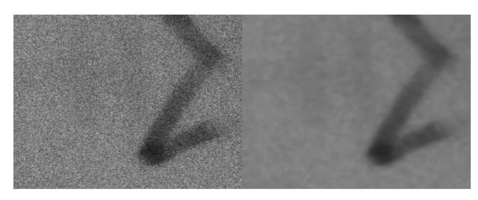
Temporal averaging

Commercial devices generally implement only **real-time temporal averaging** to reduce the quantum noise by exploiting the temporal uncorrelation of successive samples for each pixel. This tends to produce **motion blurring** effects in moving scenes, which **undermine** the **preservation of edges** and, thus, the ability to identify moving objects.



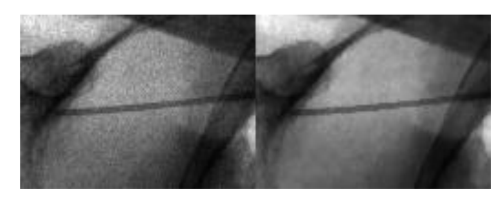
Bilateral filtering

Some **GE Healthcare** fluoroscopes implement real-time bilateral filtering, which is **computationally intensive** and requires accurate implementation on dedicated Graphics Processing Unit.
Also, it assumes the noise to be Gaussian, thus not achieving optimal results and still producing **blurring effects**.



Noise Variance Conditioned Average

The **Noise Variance Conditioned Average** (NVCA) algorithm exploits the *a priori* knowledge of noise statistics to **preserve edges** by performing a **conditioned spatio-temporal moving average** that excludes all those pixels which don't belong to the local noise statistic of the filtered pixel and are most likely to lie over edges between different objects. It has a **low computational complexity** which makes it suitable for **hardware** implementations. However, it needs **accurate selection** of filter parameters to obtain optimal results.



PURPOSES

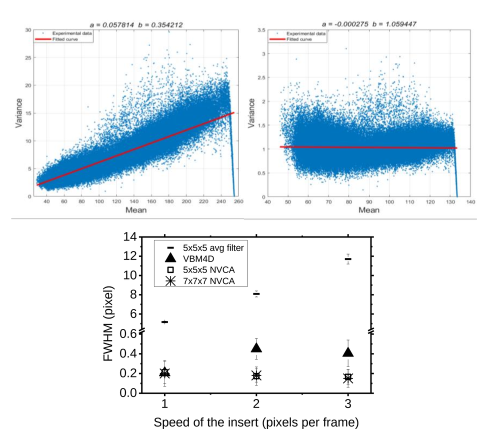
- In-depth analysis of NVCA performances and comparison with state-of-the-art algorithms
- Improvement of the trade-off between noise reduction and edge preservation for the NVCA algorithm

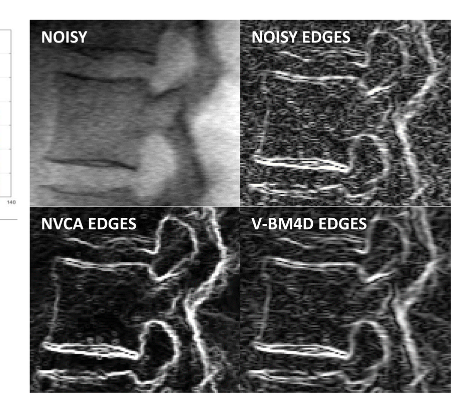
METHODS

- Comparison with V-BM4D
  - Noise variance stabilization via **Anscombe transform**
  - **Comparison** of **denoising** and **edge blurring** in moving scenes of synthetic and real fluoroscopic sequences
  - **Comparison** of **edge preservation** capabilities for **effective edge detection** in a real spine fluoroscopic sequence
- Identification of optimal parameters through different IQA indices
  - **Filtering** of a synthetic fluoroscopic sequence corrupted by simulated Poisson noise, with **all combinations of values for NVCA parameters** within certain ranges
  - **Identification** and **comparison** of **best** filtering results based on **different Image Quality Assessment (IQA)** scores
- Hardware implementation of improved NVCA algorithm
  - **Separated temporal and spatial filtering**
  - **IIR** implementation of temporal filters to **reduce frame memory**
  - **Hardware** implementation on the smallest **Xilinx StratixIV FPGA**

RESULTS

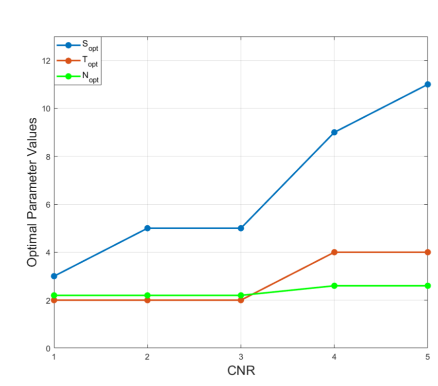
- Comparison with V-BM4D
  - **NVCA** provided **better edge preservation** than V-BM4D, in **low-dose** fluoroscopic sequences
  - **V-BM4D** performances **worsened** with growing objects **speed**, unlike **NVCA**, which provided **good** edge preservation **regardless** of objects speed

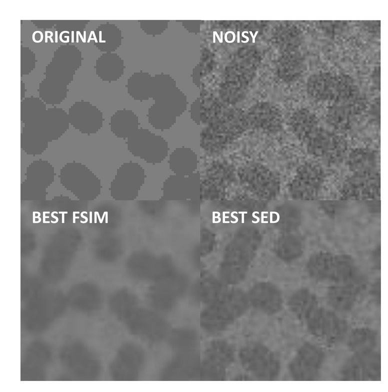




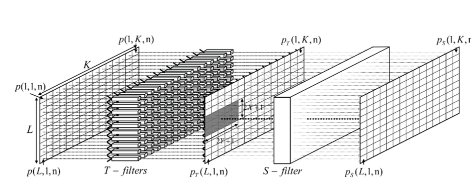
- Comparison between Feature Similarity index (FSIM) and Sensitivity of Edge Detection (SED)
  - **SED** identified the **most edge-aware** denoising, especially for **low CNR**
  - **Optimal values** for NVCA parameters **decrease** with **CNR**

	S_{opt}	T_{opt}	N_{opt}	$FSIM$	SED
V_{noise}	-	-	-	0.54	0.65
V_{FSIM}	5	3	3.4	0.87	0.57
V_{SED}	3	2	2.2	0.76	0.69

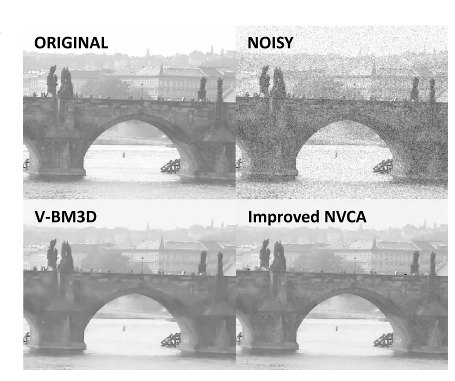




- Hardware implementation of improved NVCA algorithm
  - Reduced computational complexity
  - 22% usage of hardware resources
  - Real-time operation at a frame rate of **49 fps** and a resolution of **1024x1024 pixels**



Denoising method	$PSNR_{out}$ *(dB)*	$SSIM_{out}$
4-PDE	31.7	0.855
BM3D	36.4	0.963
VBM3D	38.2	0.973
BM3Dc	37.5	0.975
NLM	36.2	0.980
UINTA	28.9	0.879
STGSM	36.9	0.971
Improved NVCA	40.0	0.981



COLLABORATIONS

Western Sydney University; the MARCS institute for brain, behaviour and development; Macquarie University; Aston University Birmingham; Fondazione Salvatore Maugeri; Reykjavik University; IMT Atlantique Bretagne-Pays de la Loire École Mines-Télécom

PROJECTS

- PI-EVO ONC. DELUXE

FUTURE DEVELOPMENTS

- Extended performance analysis of improved NVCA algorithm and identification of optimal parameters as functions of objects shape, dimension, speed and CNR.
- Acquisition and processing of very low-dose, raw fluoroscopic sequences to assess the performances of NVCA in critical conditions
- Characterization of fluoroscope noise as function of X-ray tube settings
- Hardware implementation of improved NVCA algorithm on a System-on-Chip platform via High-Level Synthesis, to be embedded in a real fluoroscope