Intelligent medical devices and systems for telemedicine

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I. Introduction

- Health:
  - Worldwide major concern nowadays
  - Developed countries: increase of # of dependent people
  - Countries in development: insufficient access to health
- E-Health = ICT + Health
  - One of the main approaches to downscale health cost
  - Fifth axis of research of yhe SMART Labex for transversal applications
- E-Health and Computational Social and Behavioral Sciences
  - E-Health = application domain for Computational Social and Behavioral Sciences
  - Conversely E-Health research => tools for Behavioral Sciences
- Several case studies from projects of the SYEL research team of LIP6

Outline

I. Introduction

II. Implantable devices

III. “Medical device” certified image compression

IV. Telemedicine systems

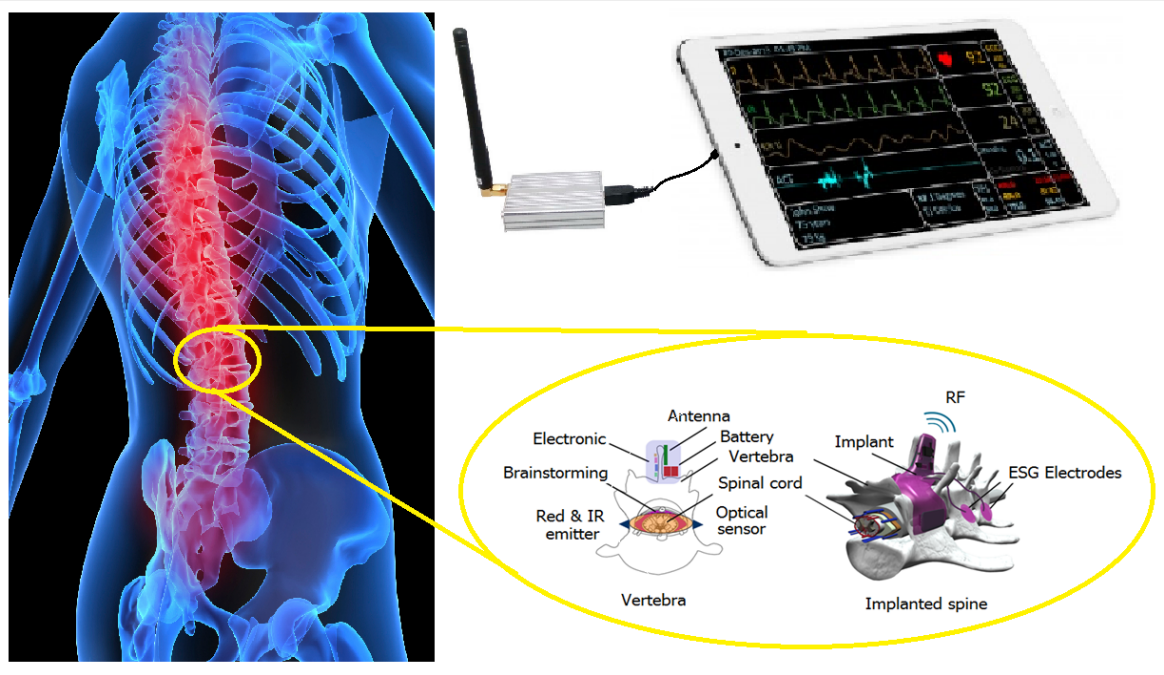
V. Conclusions and perspectives

II. Implantable devices

Implantable devices

- Medical examines performed in specific conditions
  - Hospital, dedicated laboratories, etc
- 1st Issue: Bias
  - Specific conditions ≠ from real life conditions => bias in the diagnosis
- 2nd issue: Cost
  - Specific conditions => high cost of medical examines
- => Development of new sensors for the chronical acquisition of physiological signals to monitor functional activity of the patients in their everyday life
- Case study: implantable devices
  - ☹ Invasive, very long developments
  - ☺ Once implanted, people tend to forget them
- => Suitable for extreme cases:
  - Pacemakers
  - Deep Brain Stimulation for Parkinson therapy

SpinalCOM



Communicating implant for the multimodal imaging of the spinal cord

Context

- Pathologies of the spinal cord
  - Public health problem

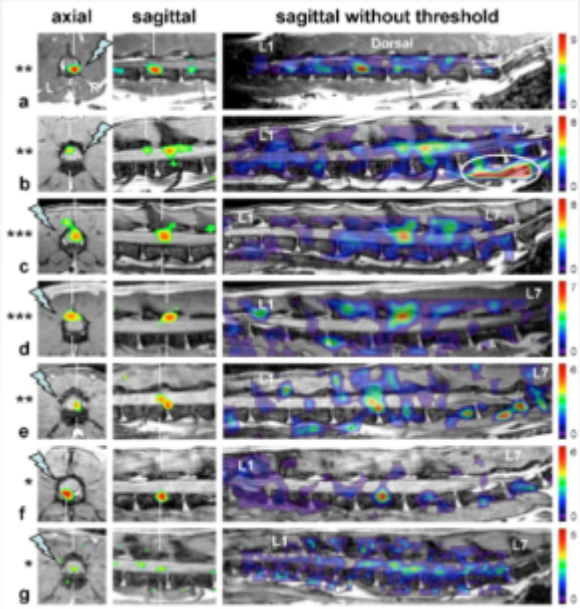
State of the art

- Current technique
  - Magnetic Resonance Imaging (MRI)
    - Insufficient for diagnosis and monitoring

Total immobility
+ Not chronical

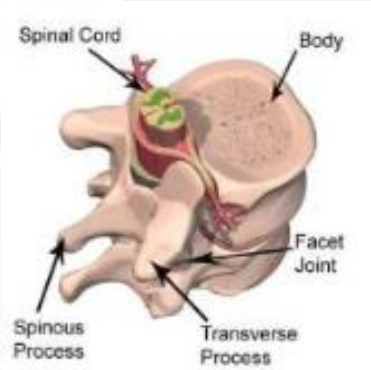
Limited resolution +
Physiological noise

Functional MRI during development



Need

- In addition to structural imaging, doctors need an ambulatory measurement tool
  - To evaluate the functional status of the spinal cord in the daily activity
  - To establish prognostic of recovery
  - To measure induced changes by
    - Pharmacological agents
    - Rehabilitation
    - …

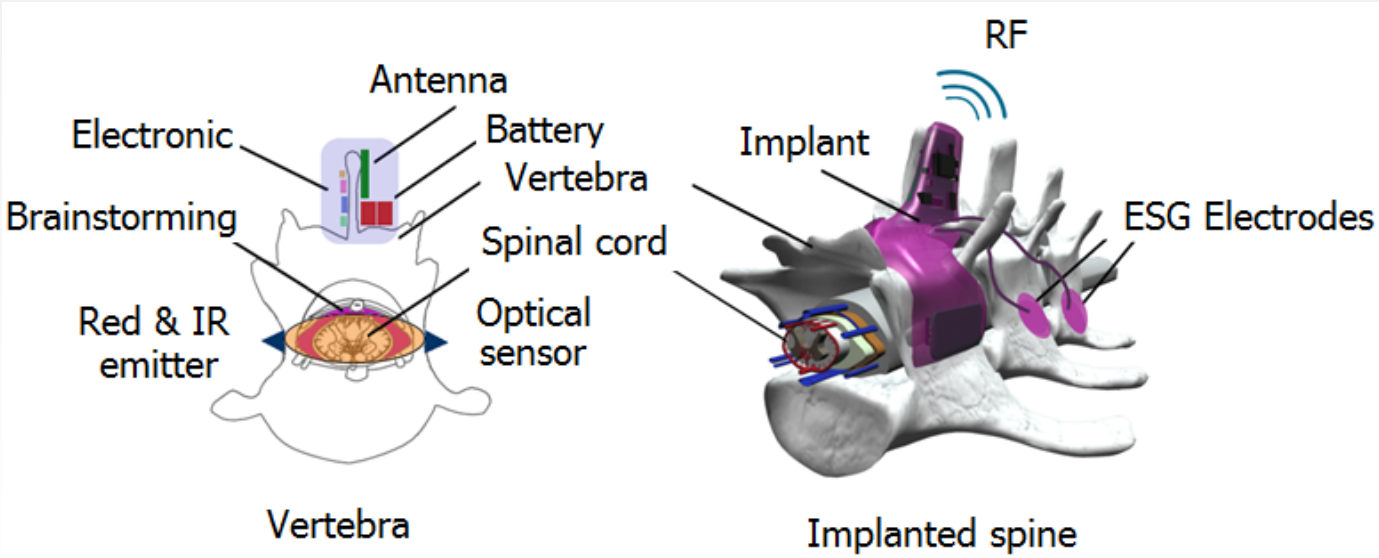


- To understand
  - The role of the spinal cord, functionning in interaction with brain
  - Its degree of independence in some motor decisions or sensory interpretation

9

Objectives of SPINALCOM

- Development of a wireless implant to evaluate the spinal cord activity by measurement of
  - The O_2 consumption by diffuse optical
  - (The electrical activity by ElectroSpinoGraphy)
  - → In fine : Network of communicating implants

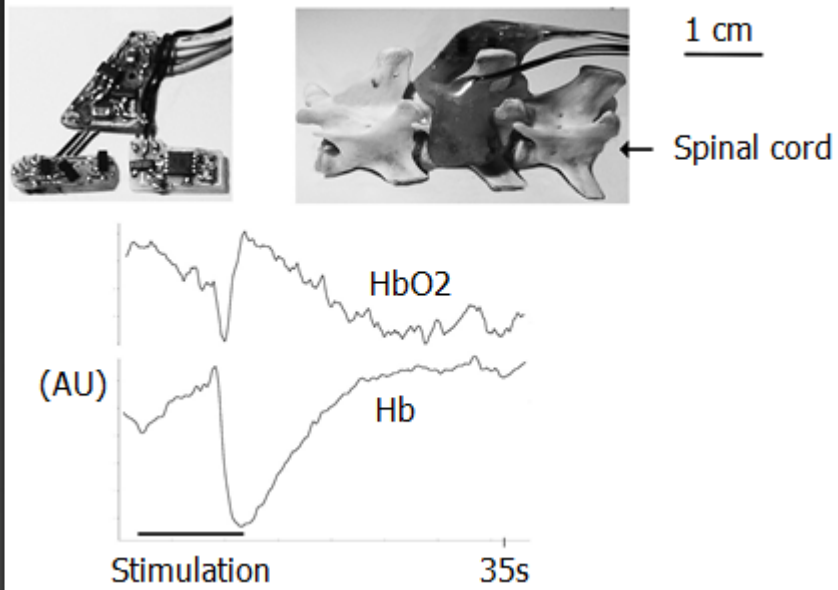


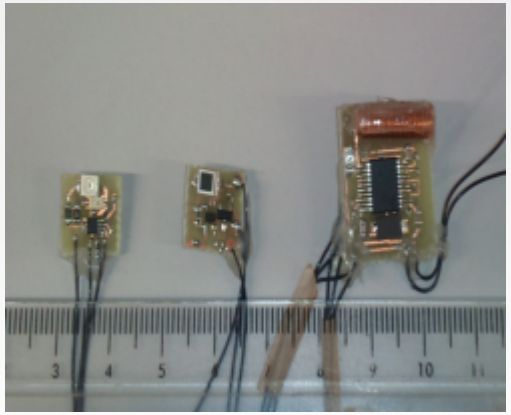
The SPINALCOM project

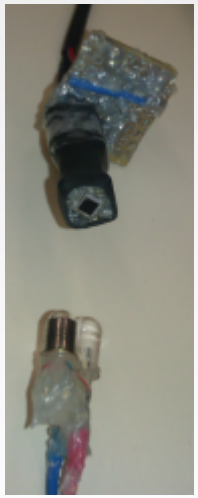
- Members:
  - LIP6/SOC/SYEL: S.Feruglio, F.Vallette, O.Tsiakaka
  - LIB: H.Benali, A.Goguin
  - AP-HP: Pradat
- Partners :
- Support: SMART Labex and EDITE School of PhD students

History

- 2009-10: 1st Prototype with wires → Meas. on cats
- 2010: Patent (Goguin, Benali et al.)
- **2011: 1st RF wireless prototype at LIP6**
- **2013: New prototype generation, tests on pigs**





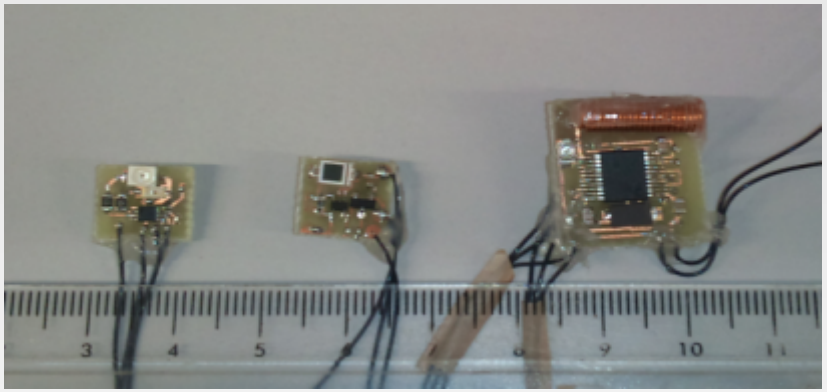


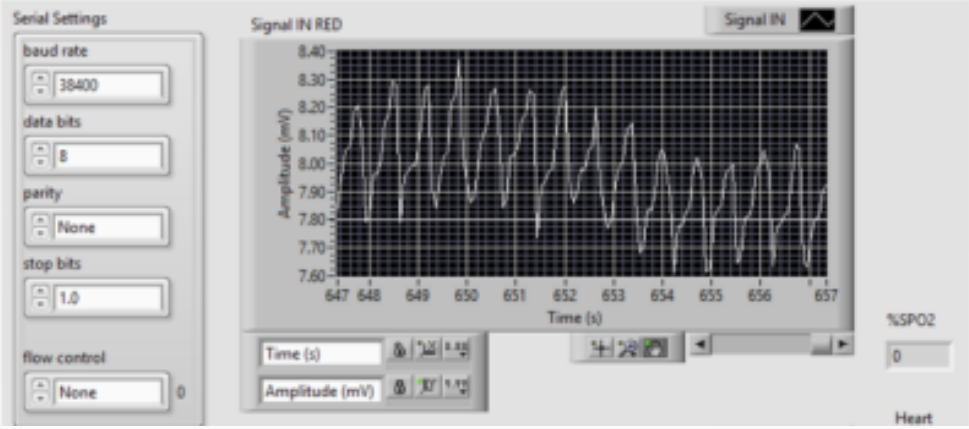
Positionning

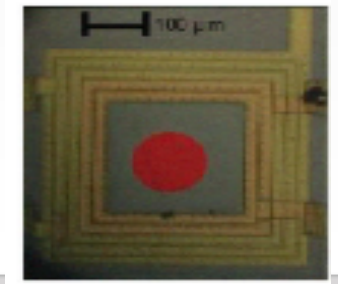
- Many
  - Digital oximeter systems
    - But implantable oximeter on simple artery is at the research level
  - Informations about bones and brain
- However, few information about the spinal cord
  - Dynamic optical model is complex
  - No real functional information about the spinal cord
- Modeling of this kind of opto-electrical system in its environment has never been done

Preliminary results

- Prototyping





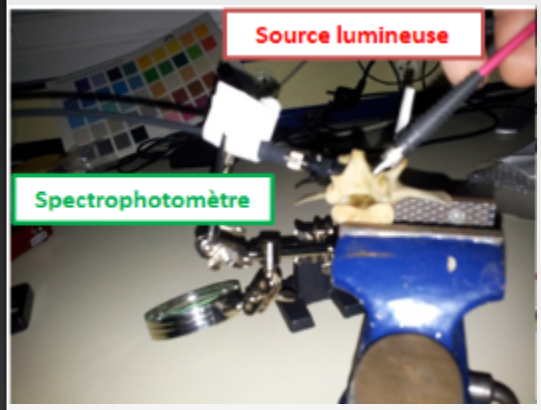


Study of new architecture for ASIC

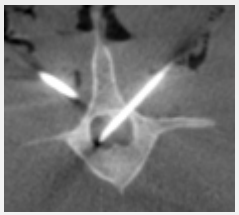
4 responses in the same pixel

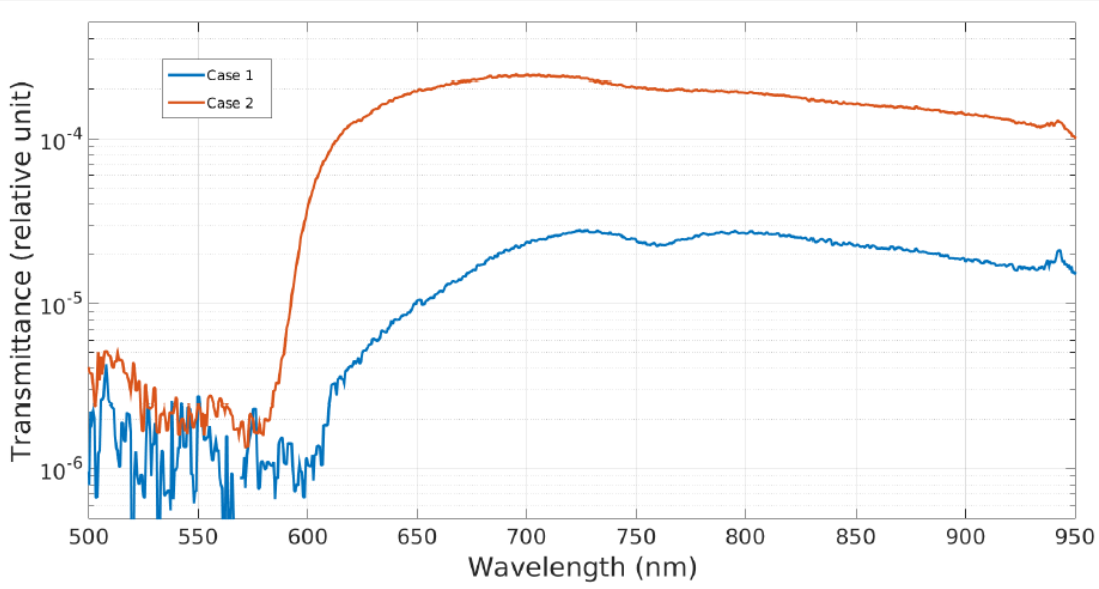
Preliminary results

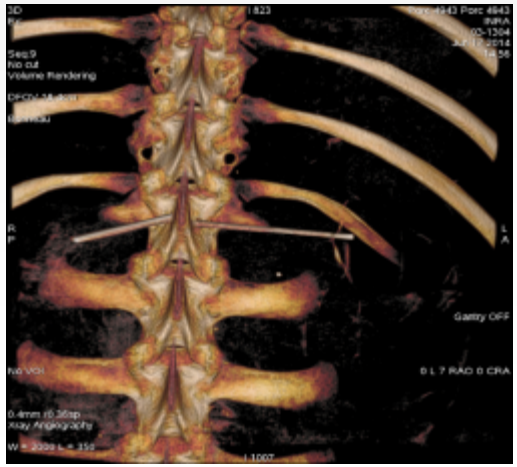
- Spectral responses with spectrophotometer



- Vertebra alone
- On pig
  - In and out of vertebra with

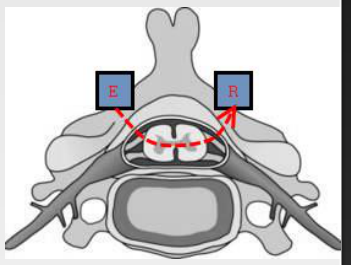


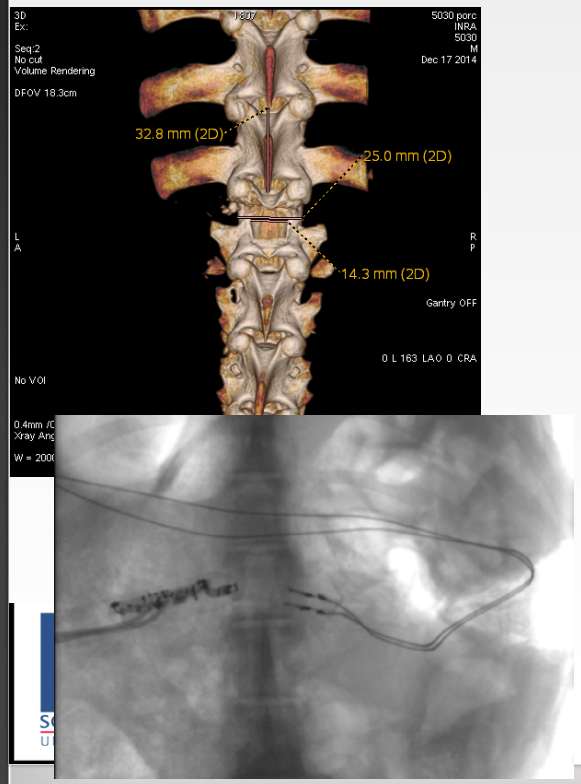


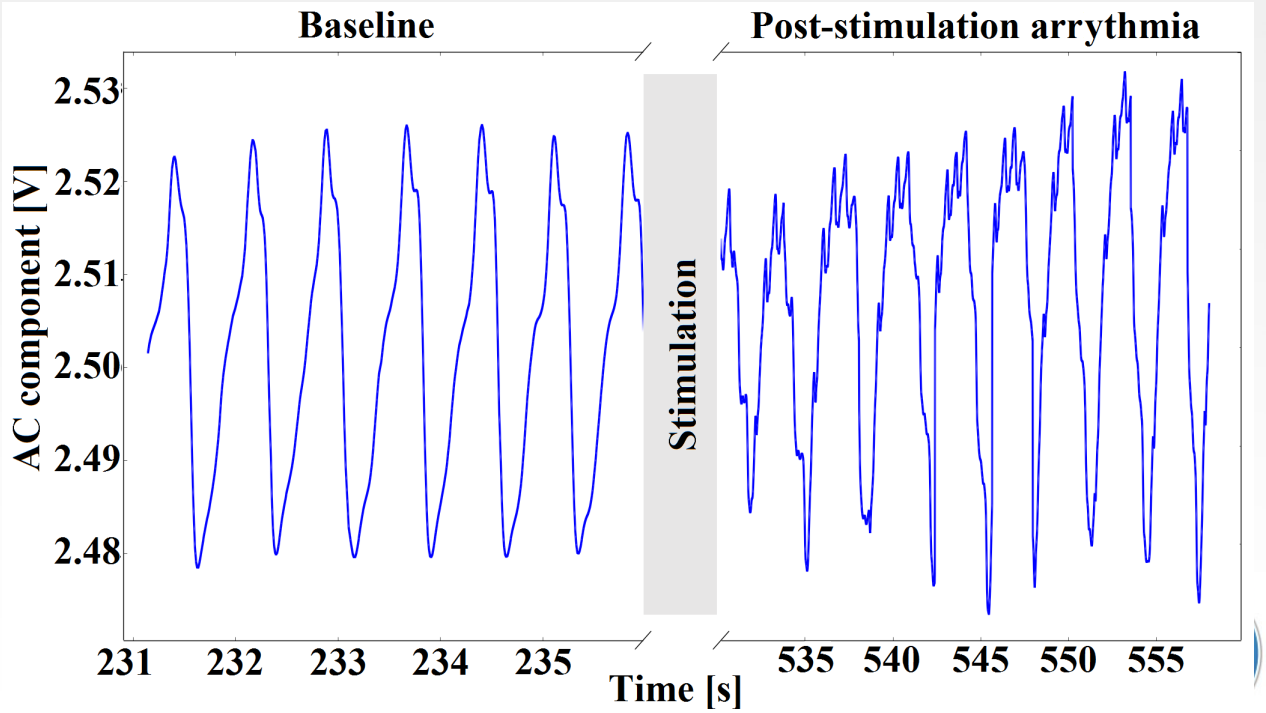


Preliminary results

- Hemodynamic response of the spinal cord
  - In pig (T14)
    - In and out of vertebra → Demonstrate feasibility







Conclusions and perspectives

- Preliminary results are encouraging
- Long term research on implanted devices
  - Suitable for extreme cases:
    - Pacemakers
    - Deep Brain Stimulation for Parkinson therapy
    - Spinal cord injury
- Development of new sensors for the chronical acquisition of physiological signals to monitor functional activity of the patients in their everyday life

III. “Medical device” certified image compression

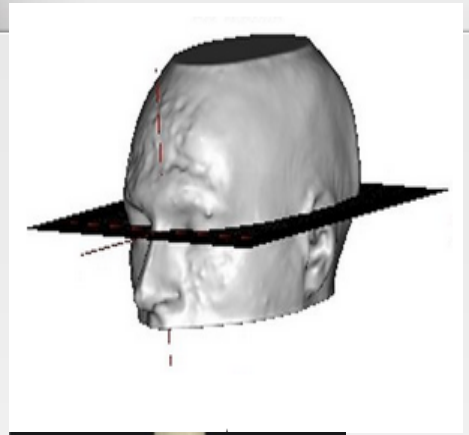
“Medical device”: the case of images

- Medical images are more and more used for diagnostic
- 1st Issue: Storage
  - Amazing increase of health data => need for compression
- 2nd issue: Quality
  - Diagnostic => data quality preserved through compression
- => Development of new algorithms for lossy image compression at diagnostic quality
  - Certifiable / certified as “medical device”

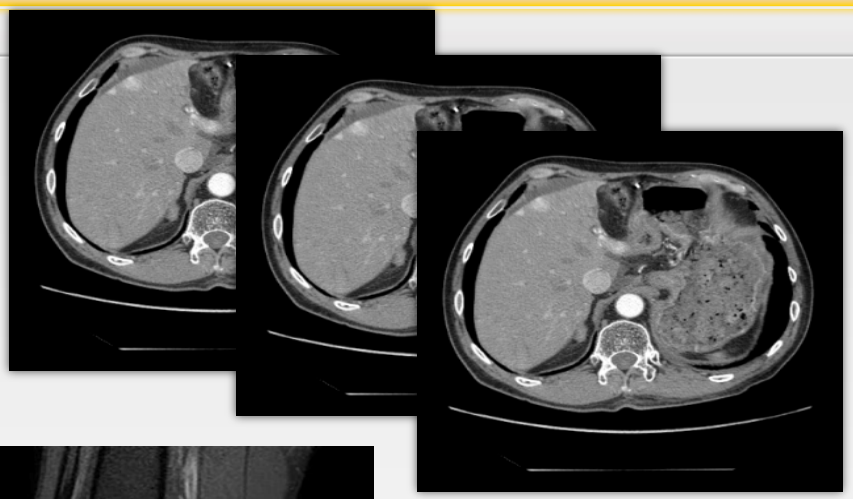
The WARM Project

- Objective: lossy compression of medical images sequences at diagnostic quality
- Participants from LIP6: Imen Mehdhbi, Khalil Hachicha and Patrick Garda
- Support: FEDER 2011 – 2013
- Other partners:
  - Companies: CIRA, PARTELEC
  - Laboratories: ETIS, HEGP

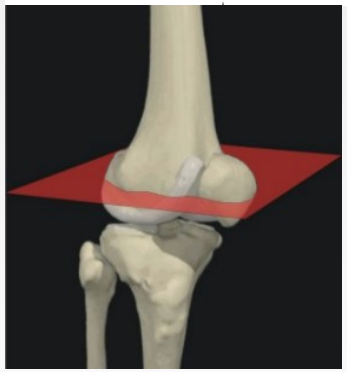
Sequences of 2D medical images



CT scan



1000 slices



IRM

> 1GB

500 slices

Angiography

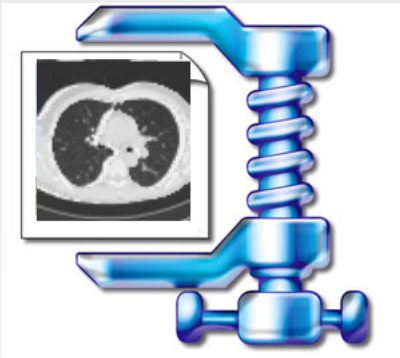
Compression of medical images: state of the art

Lossless compression

- ✓ Exact reproduction of original data
- ✗ Low compression rates: 3 : 1 to 6 : 1

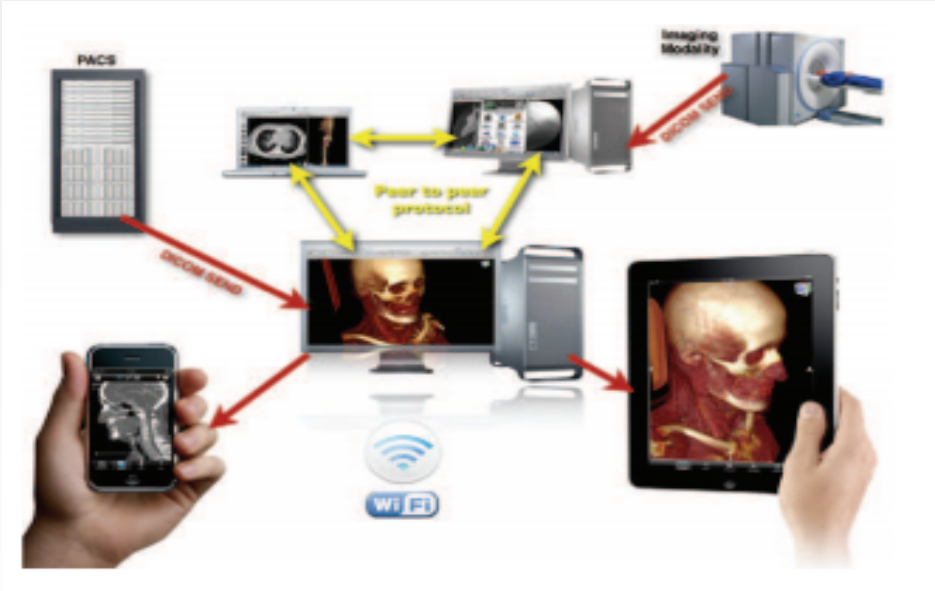
Lossy compression

- ✓ High compression rates: 10 :1 to 50 :1
- ✗ Some informations can be lost through the compression / decompression process



Compression of medical images sequences: goal

How to compress sequences of medical images, at a high compression rate while keeping a quality suffisient for diagnostics ?

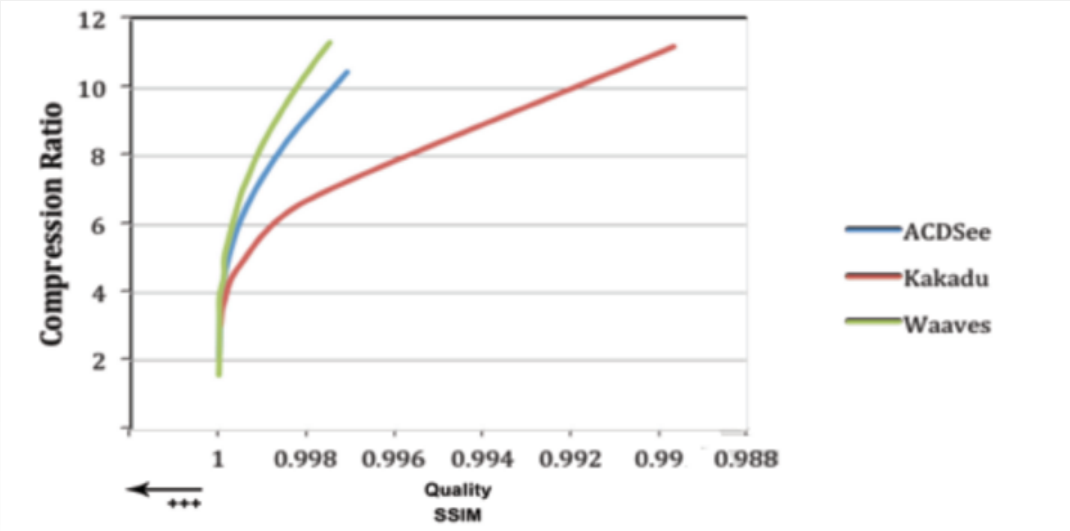


State of the art

- JPEG et JPEG2000
  - With recommandations (ACR, HAS, etc) to prevent excessive image degradations
- =>
  - Artifacts affect quality and could prevent diagnostis
  - Insufficient compression rates.

A specific coder: WAAVES

- Certified as a medical device for still images (CE)
- Compatible with DICOM
- Lossy compression at diagnostic quality with rates up to 90 : 1



Courtesy of Didier Heudes, INSERM / HEGP

MMWaaves: Mask Motion Waaves

- UPMC Patent with international extension
  - Method and device for processing image sequences with masking

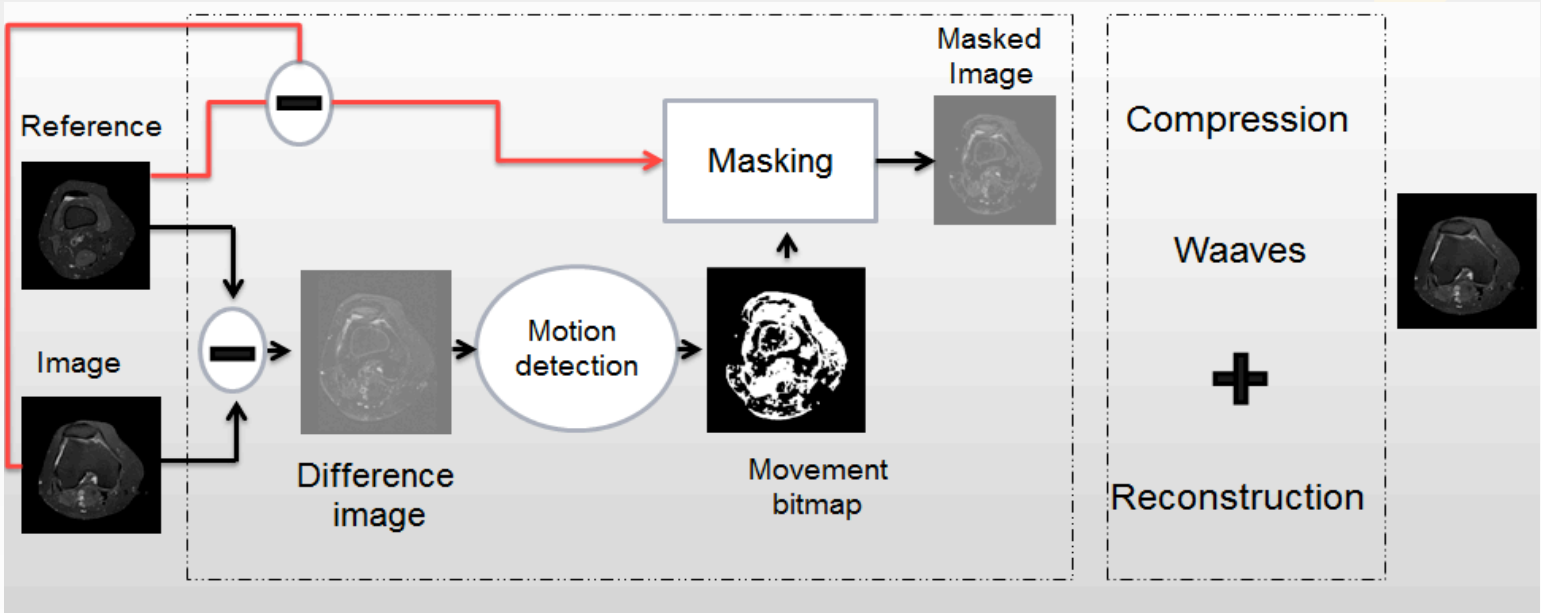
    F. Lohier, L. Lacassagne, and P. Garda. September 10, 2008. EP Patent 1,297,494.

- Waaves
  - Certified as a medical device for still images (CE)

MMWaaves = Waaves + UPMC Patent

MMWaaves

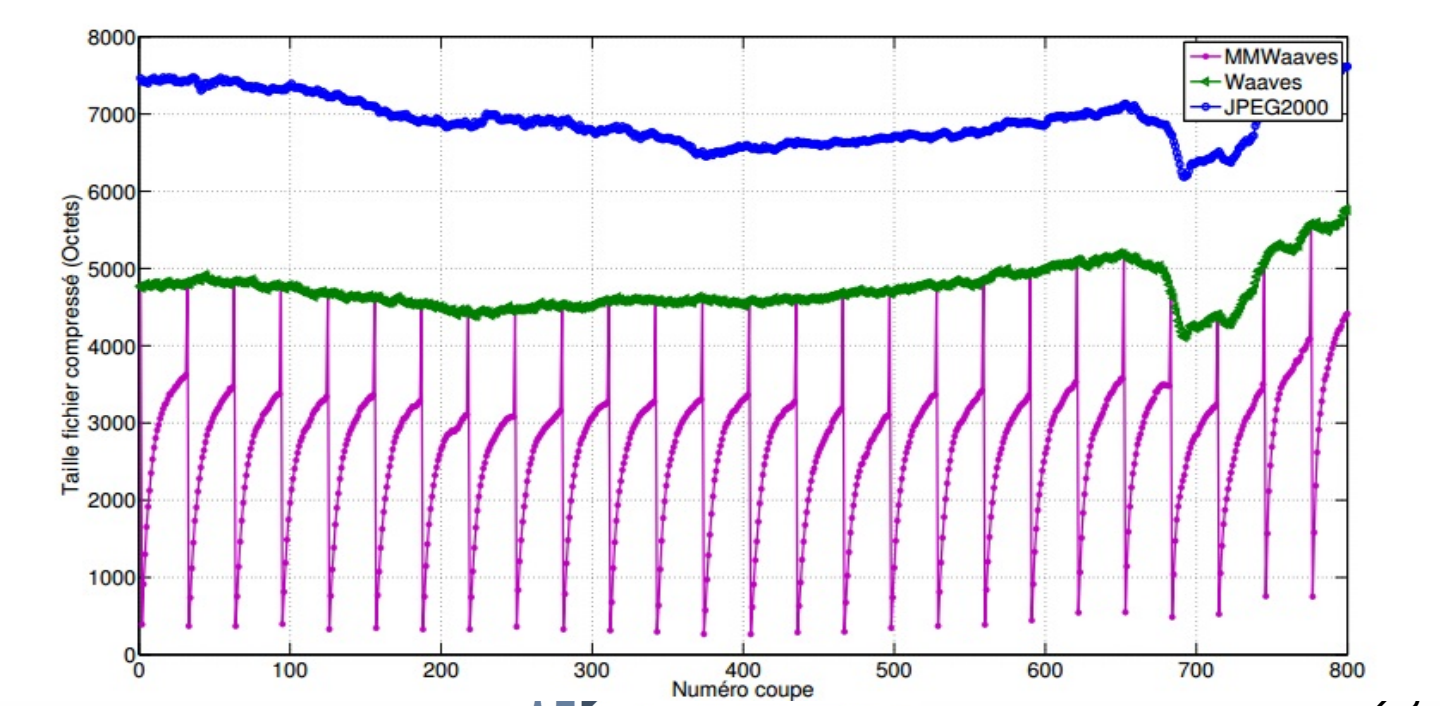
Mask Motion detection → Component Transformation → DWT & Quantization → Adaptive scanning → Bit plane Coding → HEC Coding



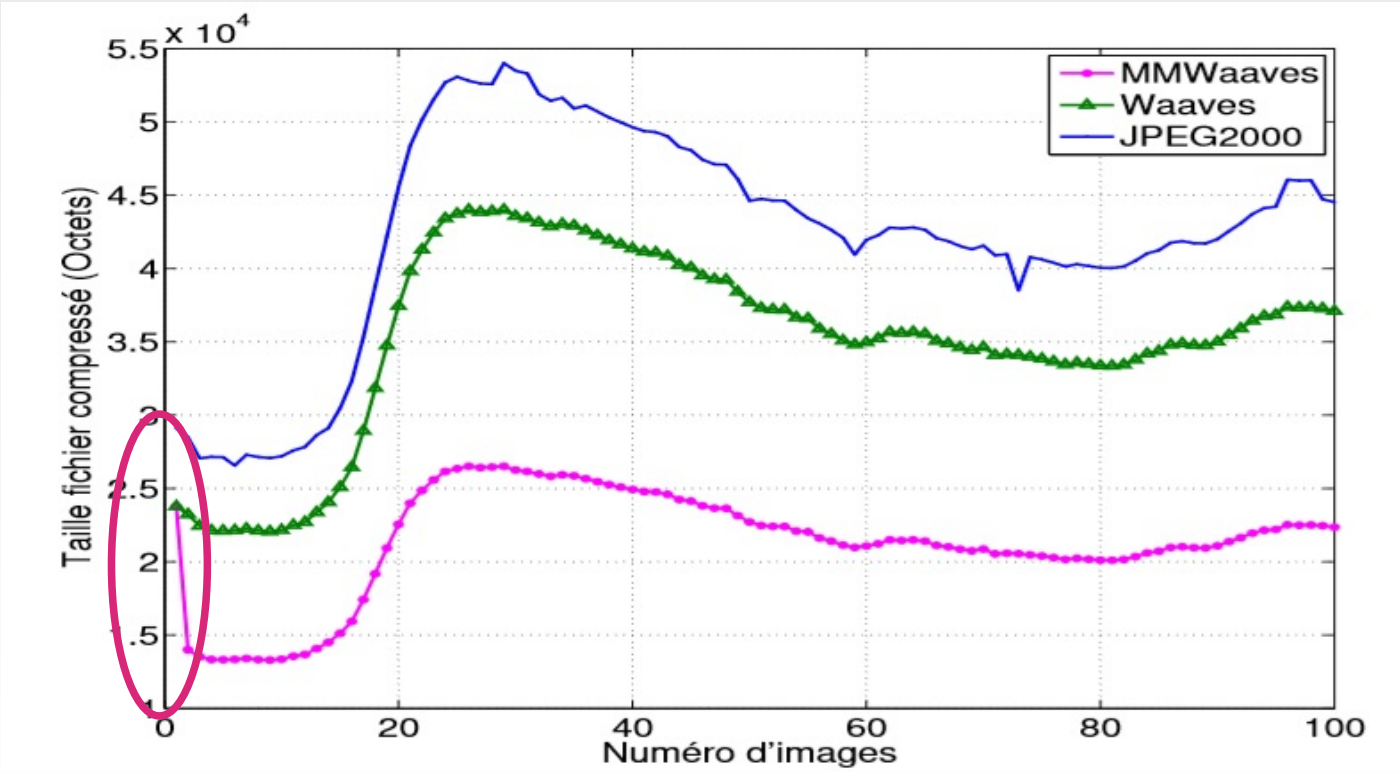
Experimental results

Compressed size w/r to reference image update: CT

Slices displacement 1.2 mm → **Reference stride = 32**

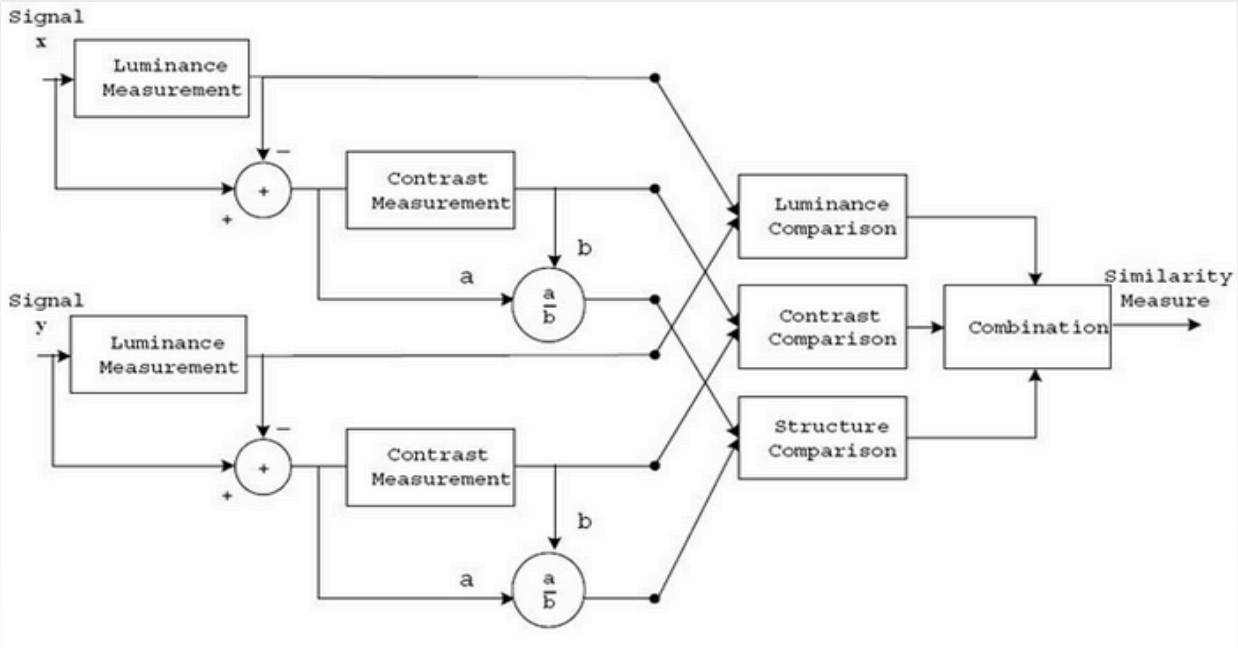


Compressed size w/r to reference image update: angiography



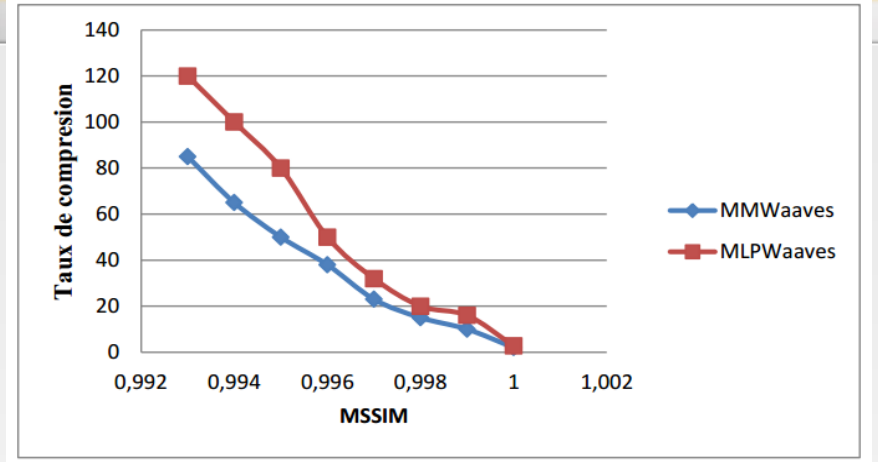
Evaluation of medical images quality

- **S**tructural **SIM**ilarity (SSIM) & Multi-scale SSIM (MS-SSIM)

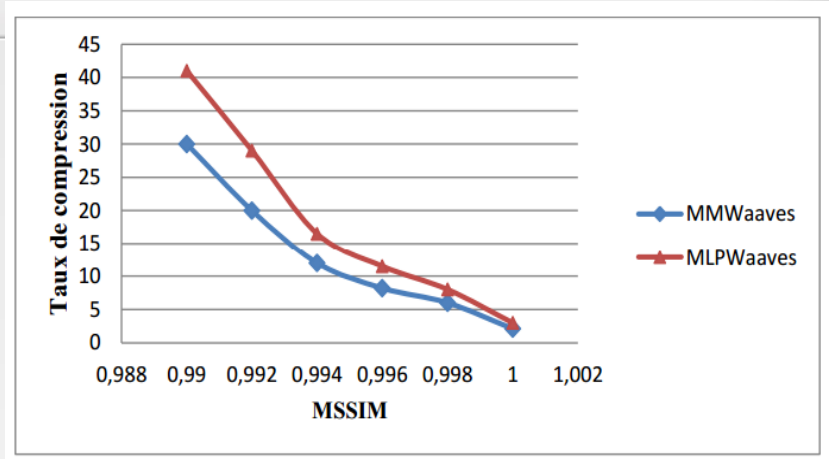


Structural similarity of images more realistic than PSNR.
Proposed by Didier Heudes, INSERM / HEGP.

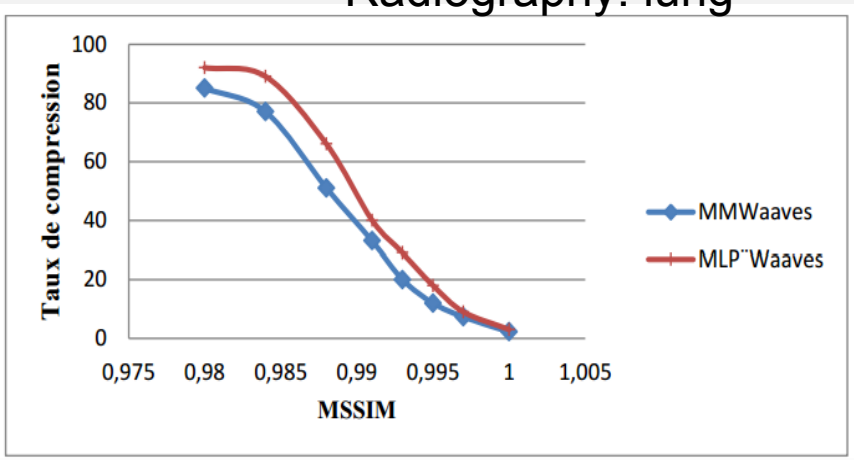
MMWaaves & MLPWaaves



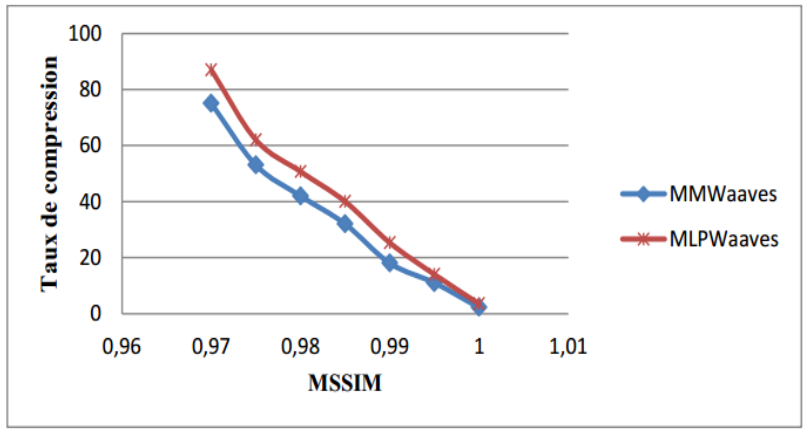
Radiography: lung



CT: brain



IRM: Knee



Coronary angiography

Conclusion and perspectives

- Two algorithms and software for the compression of medical images sequences
  - ➔MMWaaves: Gain in compression rate vs WAAVES et JPEG2000: 25% - 75%
  - ➔MLPWaaves: Gain in compression raten vs MMWAAVES: up to 40 %

- Evaluation of the medical images quality
  - ➔SSIM > 0.98

➔Feasibility of lossy compression of medical images at diagnostic quality

➔However medical validation yet to be achieved

IV. Telemedicine: Smart-EEG

Telemedicine

- Issue: access to medical experts
  - Developed countries: older population, less experts
  - Countries under development: few medical experts
- Telemedecine: Distance access to the medical expert thanks to ICT
  - Medical examine performed locally by technician or nurse
- Diagnostic requires transmission of physiological signals + audio-video of the examine performance
- Difficult diagnostic cases require precise synchronization between physiological signals, audio and video

Smart-EEG: System for Acquisition and Transmission of Multimodal Synchronised EEĠ

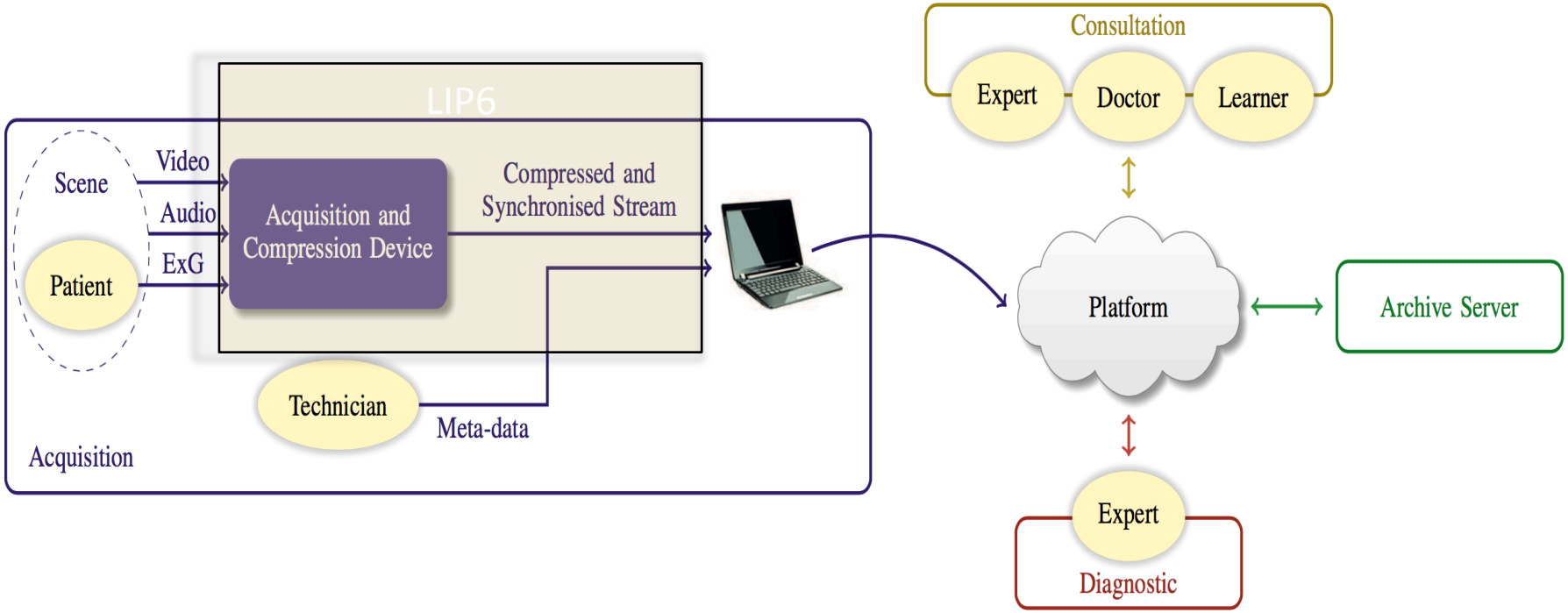
UPMC/LIP6/SOC/SYEL participants: Laurent Lambert, Zyed Ahmed, Mohamed Shaaban, Imen Dhif, Andrea Pinna, Khalil Hachicha and Patrick Garda

Other parners: ACACIA, CIRA, PARTELEC, 2CSI, ETIS, HEGP, Lariboisière Hospital

Support by FUI

Objective of the Smart-EEG project

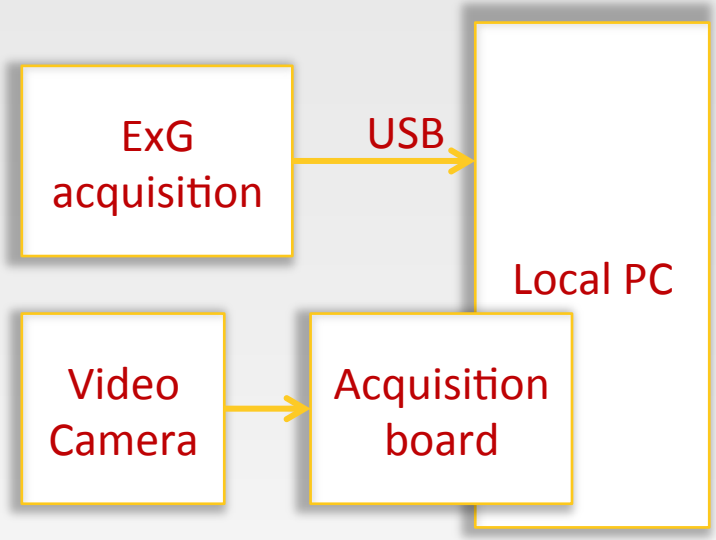
- A system for remote diagnostic



Requirements

- Importance of video signals for medical experts
  - To detect fast movements such as myoclonuses (~20 ms)
  - To measure the delay between cortical events (EEG) and their muscular response (Video and EMG)
- Need to acquire video at 100 frames/seconde

State of the art



- Physiological and video signals are grabbed by a PC with a non deterministic delay resulting from the OS, etc
- => Impossibility to synchronize precisely the two streams
- Video @ 25-30 frames/seconde

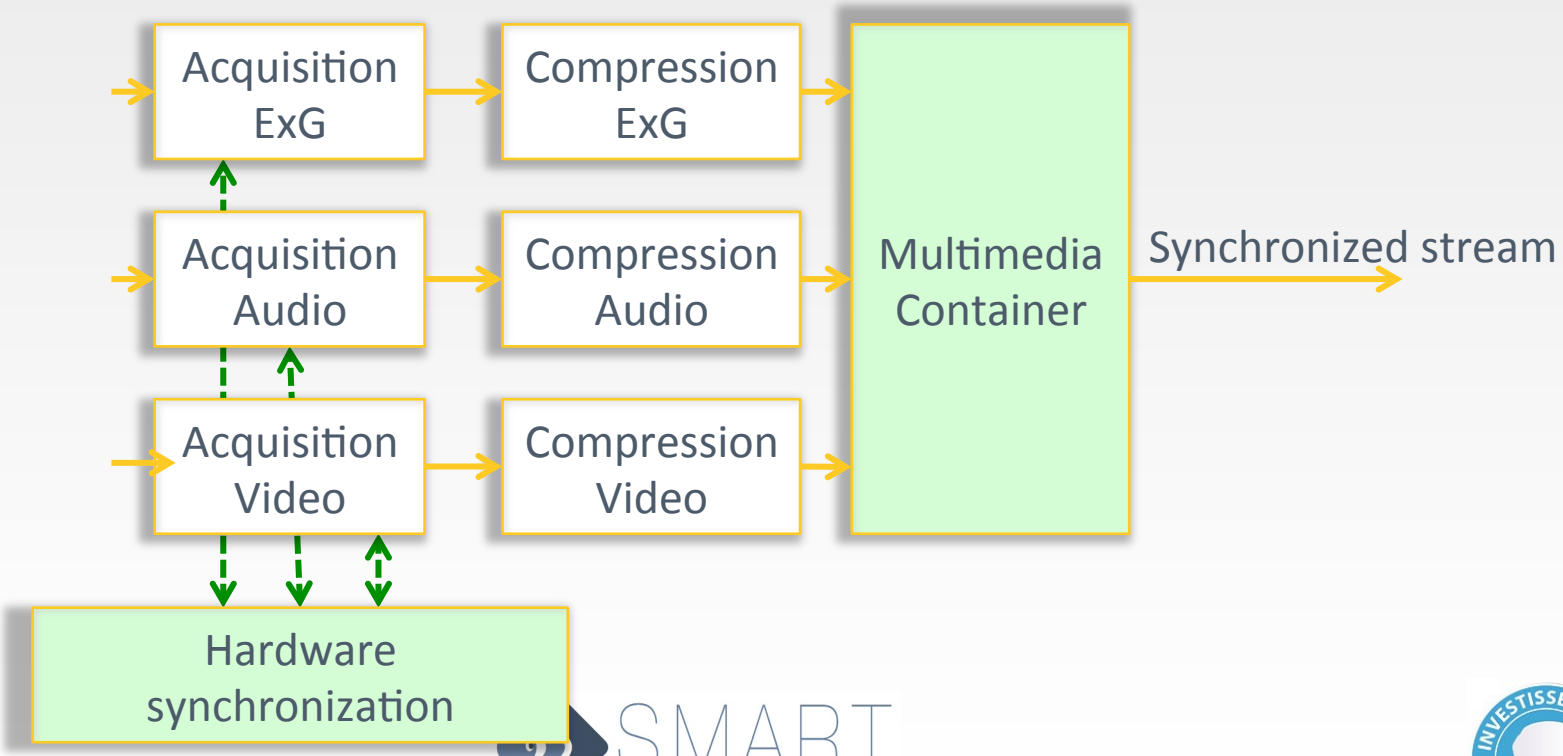
LIP6 Objectives in the project

- Design an embedded system for EEG telemedicine capable of
  - Synchronizing precisely physiological signals with video and audio.
  - Acquiring and compressing vidéo stream @ 100 frames/seconde
  - Being certified as a medical device

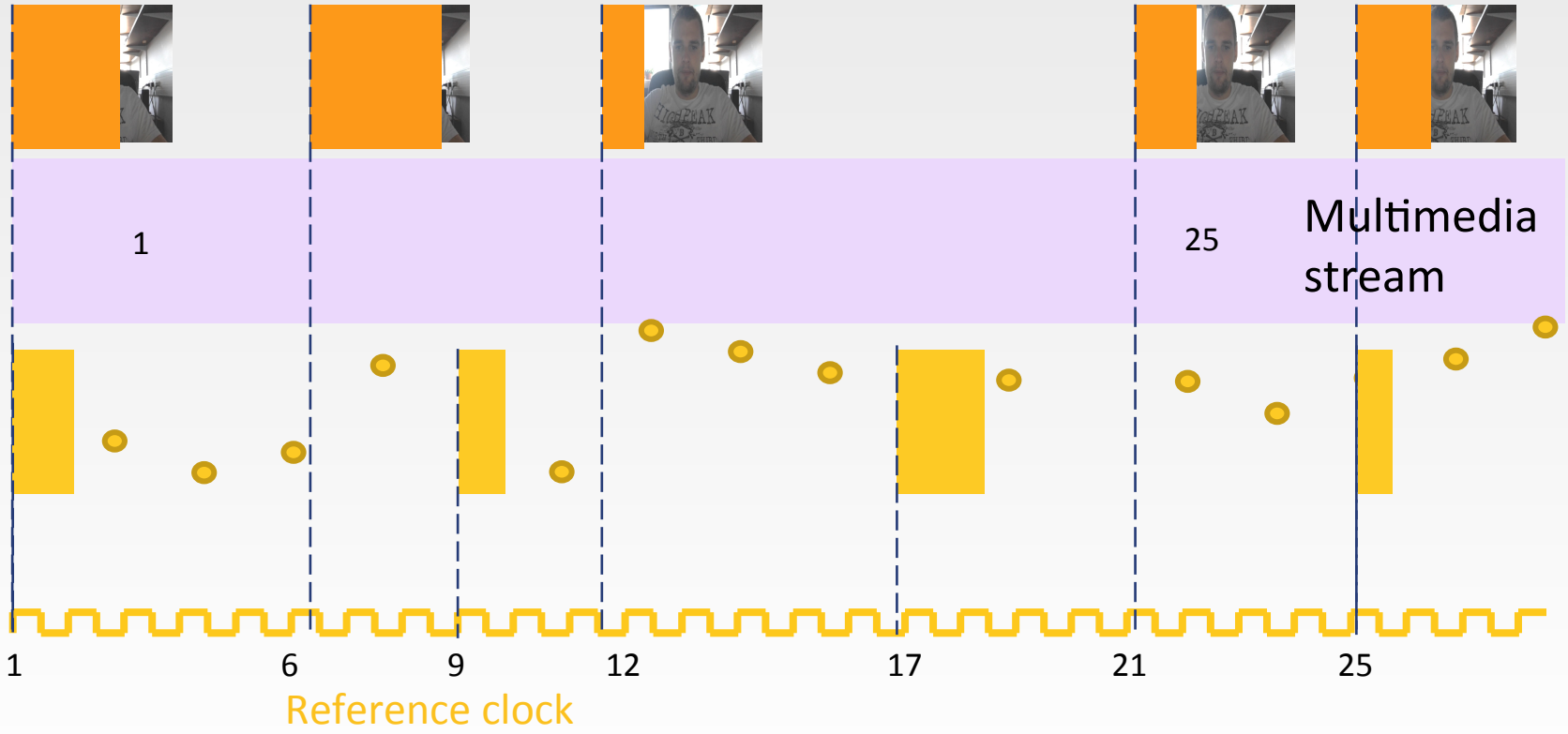
- Here focus on synchronization
  - PhD of Laurent Lambert
  - Presented at EMBC, August 26, 2015, Milano

Synchronization

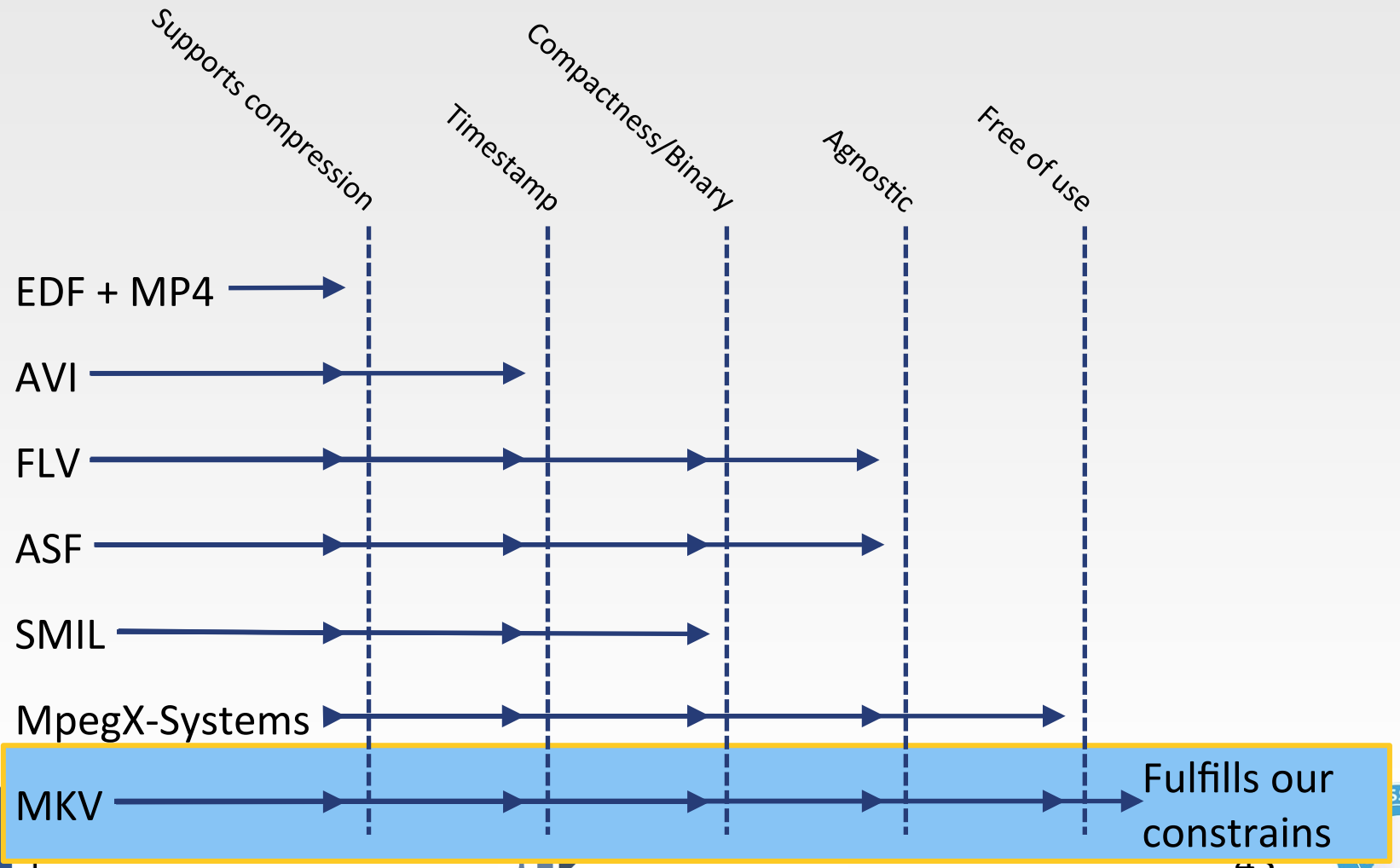
- Synchronization at two levels:
  - Hardware synchronization
  - System level synchronization



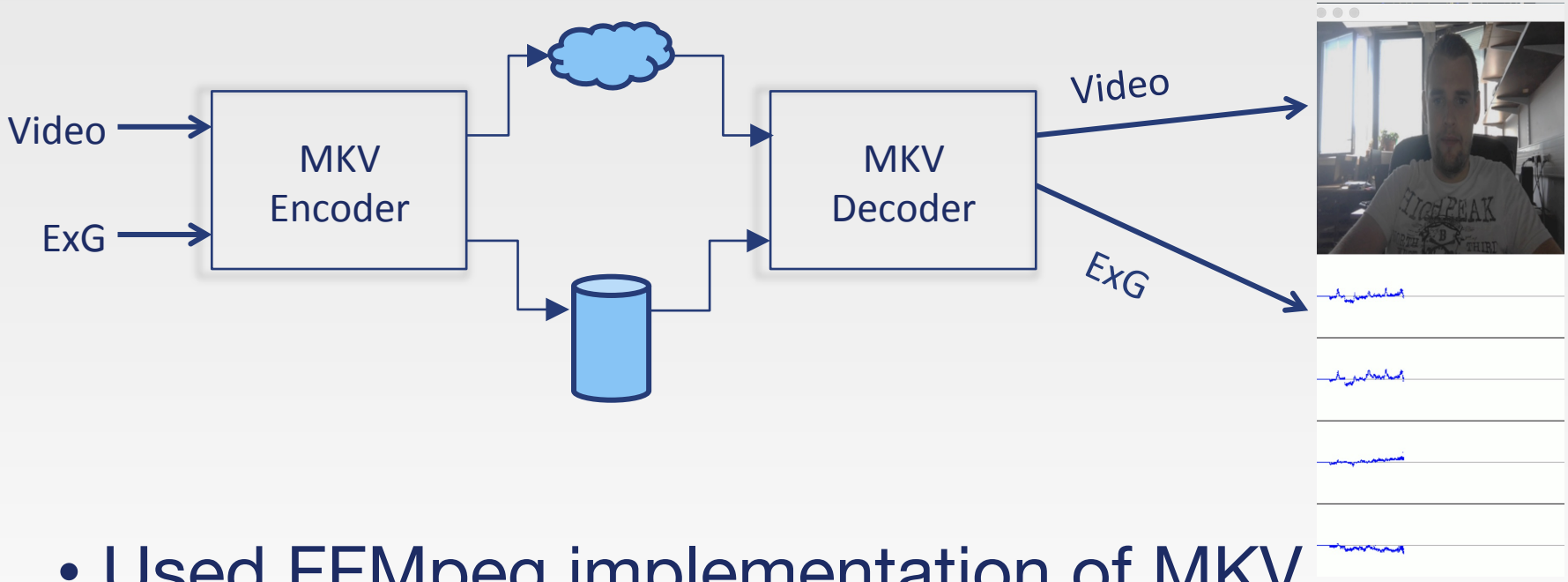
Multimedia Containers



Which Multimedia Container Format ?



Proof of Concept: MKV



- Used FFMpeg implementation of MKV
- Added a new type of track in MKV: Physiological

Conclusion and Perspectives

- Conclusion
  - Novel synchronization for multimodal exams
  - Proof of concept using MKV
  - Enhanced features with low overhead

- Perpectives
  - Exploration of Mpeg based solution
  - Coupling with hardware synchronization
  - Evaluation by medical experts

V. Conclusion and perspectives

Conclusions

- Physiological signals acquisition
  - Chronical everyday monitoring of physiological signals for medical diagnostic
- Compression and quality
  - Explosion of health data require lossy compression
  - However compression algorithms have to guarantee diagnostic quality of the reconstructed images
- Telemedicine systems
  - High frequency and precise synchronization between physiological signals, audio and video are needed for diagnostic of difficult cases
  - High-level synchronization allows compression and editing of ≠ modalities

Perspectives

- Link with the SeNSE project of SMART Labex
  - LIP6 case study on affective gaming: emotion recognition of video game players
  - Poster presented by Mrs Wenlu Yang at the COMPOSES School: "Emotion recognition with an embedded system"
  - Several other presentations at COMPOSES related to the SeNSE project

- Long term applications to computational social and behavorial sciences
  - High frequency compressed and synchronized multi-modal acquisition

Thanks

- Audience
- Organizers
- Providers of material: Sylvain Feruglio, Khalil Hachicha and Laurent Lambert
- Participants to the mentioned projects

Contacts for the projects

- SPINALCOM: Sylvain.Feruglio@upmc.fr
- WARM: Khalil.Hachicha@upmc.fr
- Smart-EEG: Patrick.Garda@upmc.fr
- SeNSE: Catherine.Achard@upmc.fr

Publications for SPINALCOM

- With SMART Labex support:
  - S. Feruglio, et al., "Opto-electrical Modeling of CMOS Buried Quad Junction Photodetector", IC-MAST, proc. in Key Engin. Materials, Trans Tech Publications, Vol. 605, pp. 470-473, 2013.
  - S. Feruglio, et al., "A CMOS Buried Quad p-n Junction Photodetector Model", IEEE Sensor J., en resoumission après corrections mineures.
  - O. Tsiakaka, et al., "Imaging of Haemodynamic Spinal Cord Activity in the Pig", IEEE NER, France, 2015.
  - O. Tsiakaka, et al., "Study of the Spinal Cord Activity in the Pig", JETSAN, France, 2015.
  - O. Tsiakaka, et al., "Experimental Study of the Pig Spinal Cord", IEEE EMBC, Italy, 2015.

- Before:
  - A. Goguin, et al., "A Low-Cost Implantable Near-Infrared Imaging System of Spinal Cord Activity in the Cat", IEEE Trans. on Biomed. Circuits and Systems, 4(5), pp. 329-335, 2010.
  - A. Goguin, et al. "Dispositif de mesure d'une activité de la moelle épinière d'un vertébré", Brevet9F-1251 cas 14 BP, et FR2952518 A1, UPMC, 2010 et "Device for measuring the activity of the spinal cord of a vertebra", Patent WO/2011/057765, 2011.

Publications for WARM

International Publications

- I. Mhedhbi, K. Hachicha, P. Garda, Y. Bai, B. Granado, S. Topin, S. Hochberg : "Towards a mobile implementation of Waaves for Certified Medical Image Compression in E-health Applications", International Conference on Wireless Mobile Communication and Healthcare (MOBILHEALTH), Paris, France, pp. 1-8 (2012)
- Y. Bai, S.Z. Ahmed, I. Mhedhbi, K. Hachicha, P. Garda, B. Granado : "FPGA vs DSP : A throughput and power efficiency comparison for Hierarchical Enumerative Coding", Very Large Scale Integration (VLSI-SoC), 2013 IFIP/IEEE 21st International Conference on , vol., no., pp.318,321, 7-9 Oct. 2013
- I. Mhedhbi, F. Kaddouh, K. Hachicha, D. Heudes, S. Hochberg, P. Garda : "Mask Motion Adaptive medical image coding", IEEE-EMBS International Conferences on Biomedical and Health Informatics (BHI), Mai 2014, Valence.
- S.Z. Ahmed, Y. Bai, I. Dhif, L. Lambert, I. Mehdbhi, P. Garda, B. Granado, Kh.Hachicha, A. Pinna, F. Ghaffari, A. Histace, O. Romain : "SmartEEG : a multimodal tool for EEG signals", Proceedings of IEEE FTFC Conference, IEEE (Ed.), Monaco, Monaco, pp. 1-4 (2014)
- I. Mhedhbi, K. Hachicha, P. Garda : "A New Integer Energy Activity Mesure for Parallel Bit Plane Coding", The 12th IEEE International New Circuits and Systems Conference (NEWCAS), Juin 2014, Trois riviére, Canada.
- I. Mhedhbi, K. Hachicha, P. Garda : "Multithreading Parallel Bit Plane Coding", Conference on Design of Circuits and Integrated Systems (DCIS), Novembre 2014, Madrid, Spain.

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- I. Mhedhbi, K. Hachicha, P. Garda : "Compression Waaves de séquences d'images médicales par modélisation Markovienne", Colloque du GDR SOC-SIP, Paris (2012)
- I. Mhedhbi, K. Hachicha, P. Garda , Colloque du GDR SOC-SIP,Paris (2013)
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- I. Mhedhbi, K. Hachicha, P. Garda : "Parallel Bit plane for MMWaaves coding", GDR SOC-SIP, Lyon (2014)

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  - **JETSAN 2015** : *"Smart-EEG : a Tele-medicine System for EEG Exams"*, L. Lambert, I. Dhif, M. Shaaban Ibraheem, B. Granado, K. Hachicha, A. Pinna, P. Garda, N. Kubis, F. Kaddouh, D. Heudes, M. Terosiet, A. Histace, O. Romain, S. Hochberg et I. Mhedhbi. Mai 2015
- International Conferences:
  - **IEEE FTFC** : *"SmartEEG : a multimodal tool for EEG signals"*, S. Zahid Ahmed, Y. Bai, I. Dhif, L. Lambert, I. Mehdbhi, P. Garda, B. Granado, K. Hachicha, A. Pinna, F. Ghaffari, A. Histace et O. Romain. Mai 2014.
  - **Journal EURTELEMED** : *"SMART- EEG : télétransmission en électroencéphalographie"*, L. Lambert, J. Despatin, I. Dhif, I. Mhedhbi, M. Shaaban Ibraheem, S. Zahid Ahmed, B. Granado, K. Hachicha, A. Pinna, P. Garda, F. Kaddouh, Mehdi Terosiet, A. Histace, O. Romain, C. Bellet, F. Durand, JP. Commes, S. Hochberg, D. Heudes, P. Lozeron et N. Kubis. Juin 2015.
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