Technological Considerations for Future Wireless Video Capsule Endoscopy

Dr. Ilangko Balasingham

Head of Wireless Biomedical Sensor Network Research Group

Professor of Medical Signal Processing

Intervention Center, Oslo University Hospital, Oslo

and

Department of Electronics and Telecommunications

Norwegian University of Science & Technology, Trondheim

and

Institute of Clinical Medicine, University of Oslo

The Research Council of Norway

MELODY 2008 - 2017

http://www.melody-project.info

Acknowledgement

- Dr. Raul Chavez-Santiago, Dr. Pål Anders Floor, Dr. Anna Kim, Dr. Babak Moussakhani, Dr. Hieu Nguyen, Dr. Ali Khaleghi, and Prof. Tor Ramstad from the MELODY project 2009-2017.
- Dr. S-E Hamran, Norwegian Defense Research Establishment

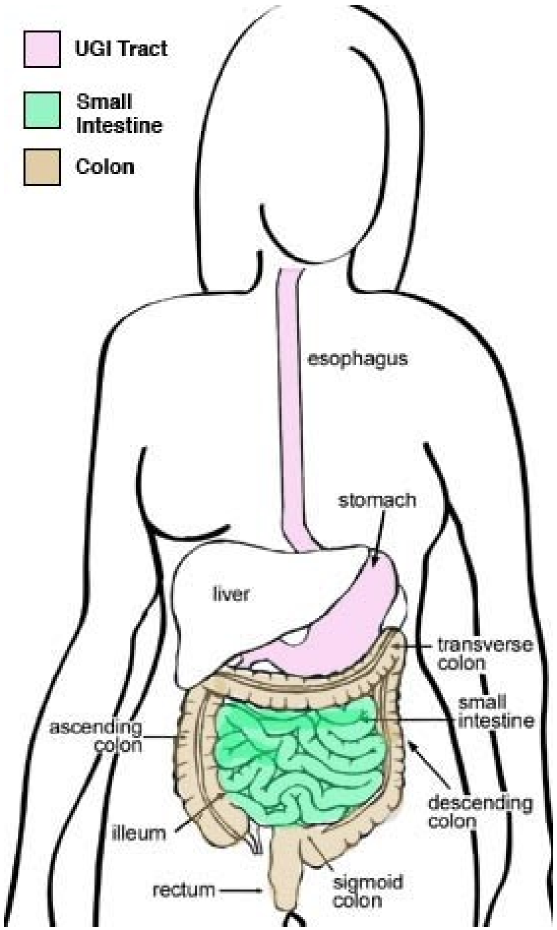
- Professor Dirk Plettemeier, Technical University of Dresden, Germany
- Professor J. Wang and Dr. D. Anzai, Nagoya Institute of Technology, Japan
- Dr. H-b Li and Dr. K. Takizawa, NICT, Japan

Outline

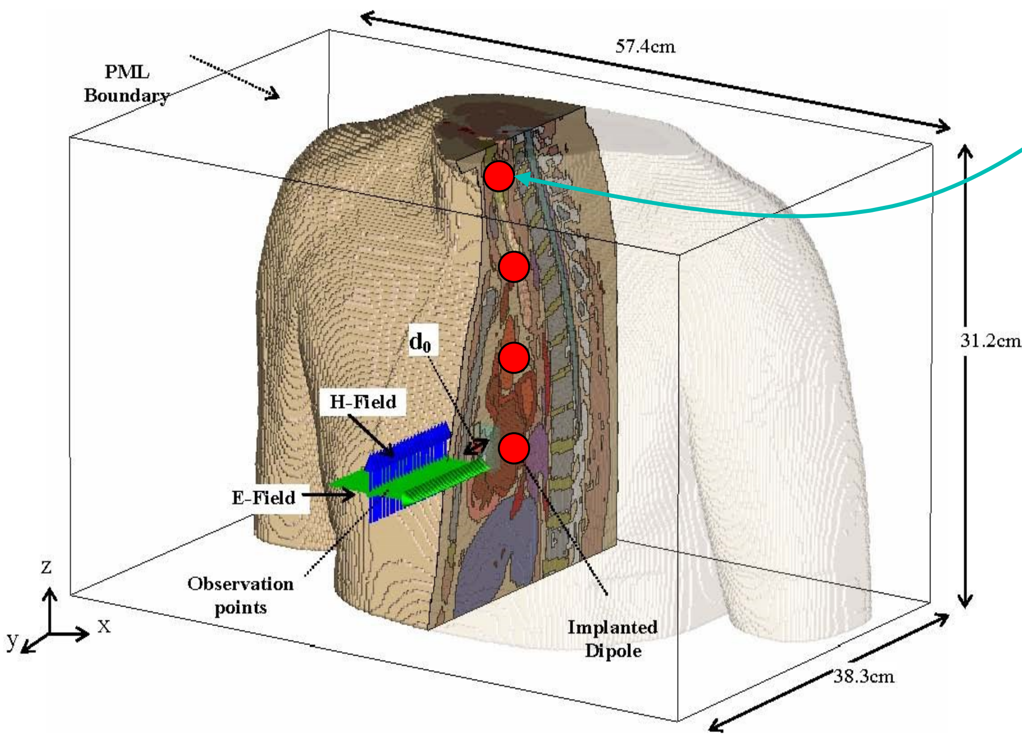
- Technological challenges
- Wireless communications
- Localization and tracking (will talk if time permits)
- Source compression
- Anomaly detection – image processing

Capsule video endoscopy

- Use for examination of gastrointestinal track for bleeding, inflammation, tumor, cancer, etc.
  - ca. 15% of male and female above 50 years old are likely to get colorectal cancer
  - early detection can cure or extend the life with a few years – screening the entire population above 50 years!
- Fiber optic cable – problems to reach small intestine – huge discomfort for the patient!



Capsule endoscopy



RecorderBelt on Patient

Application Specific Technical Challenges

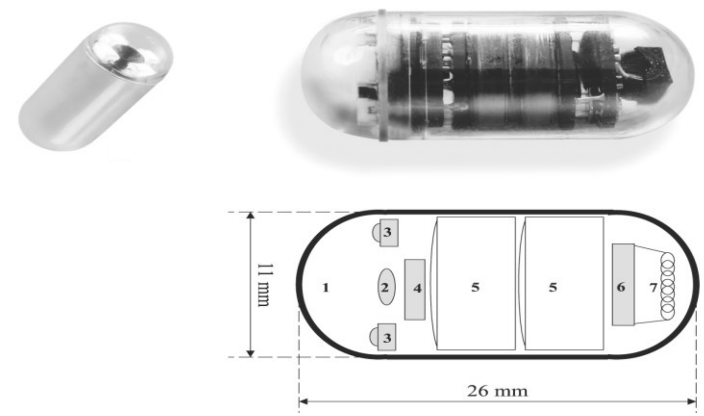
- Pathological relevant images - virtual biopsy
- High quality visual content – full HD video
- Location information of pathological changes in mm accuracy
- Remote control with navigation and tracking
- Therapy – drug delivery
- Better cleansing methods

Current Specification

Size: 11 × 26 mm
Transmission frequency: 402–405 MHz
Bandwidth: 300 kHz

Data Rate: 800 kbps
Image Rate: 2 to 10 fps
Image Resolution: 256 × 256 pixels

Power consumption: ~100 mW
Operating life: 8 hours



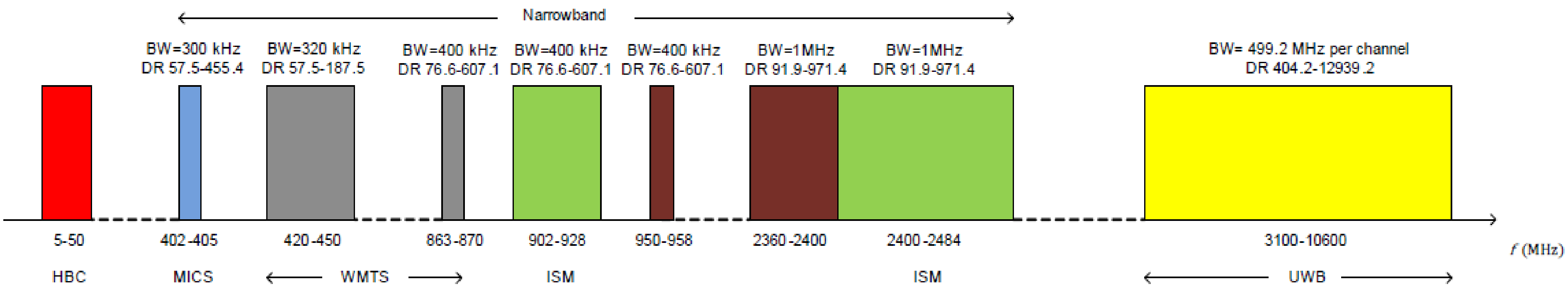
Part 1: A channel propagation model for capsule endoscopy with transceiver designs

Required characteristics for improvement

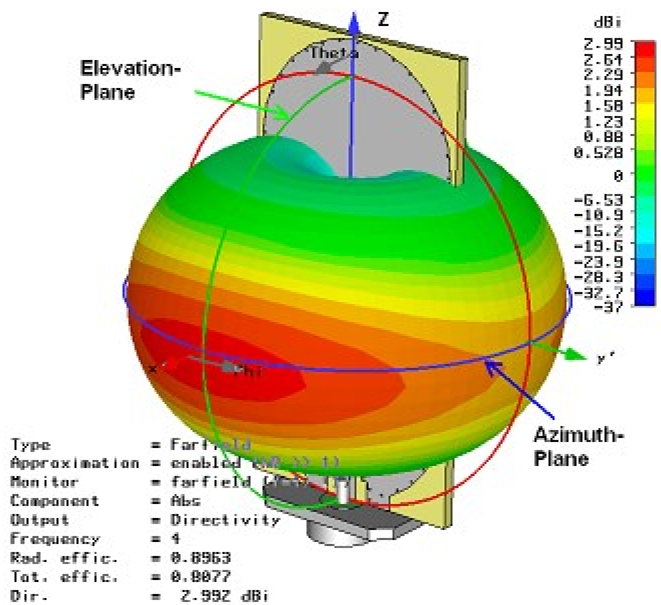
- **High data rate**
  - 73.8 Mbps for raw HD data
- **Extremely low power consumption**
  - On the order of 1 mW
- **Circuitry simplicity/integrability**
  - 0.18 μm CMOS technology
- **Reduced physical dimension**
  - 11 mm × 26 mm^2
- **Electromagnetic radiation safety**
  - SAR limits, overheating below 1 °C

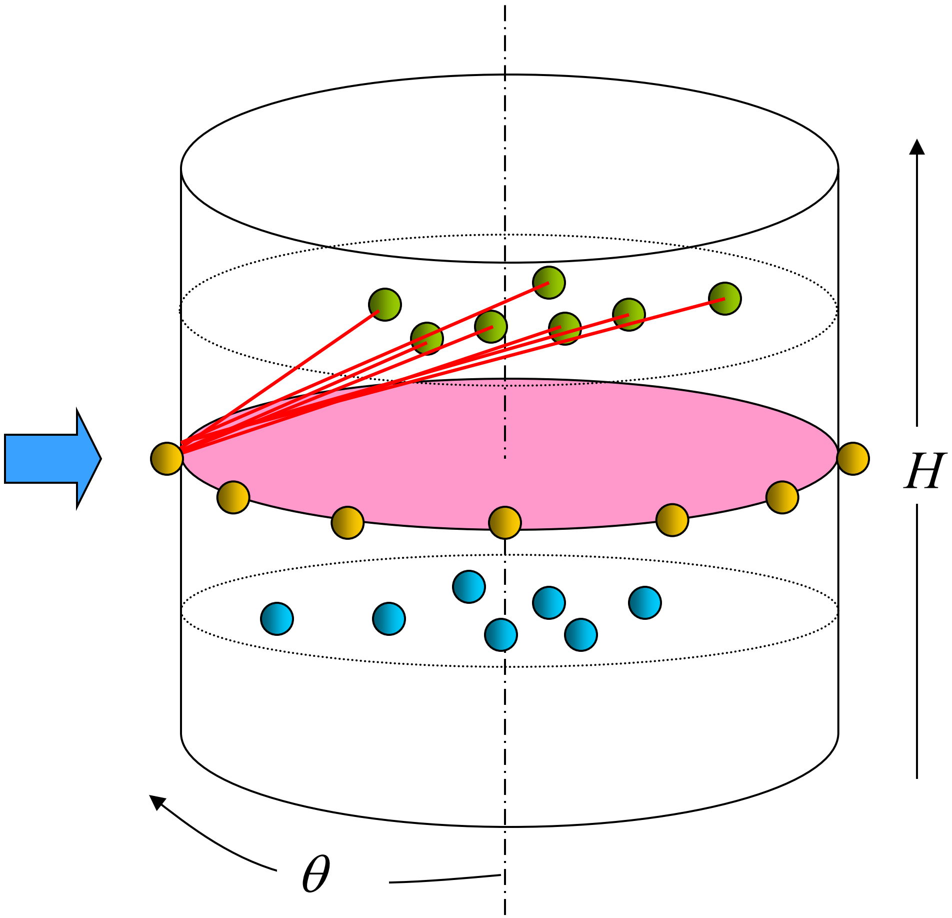
→ **Impulse Radio Ultra Wideband (IR-UWB) Technology**

Frequency Bands

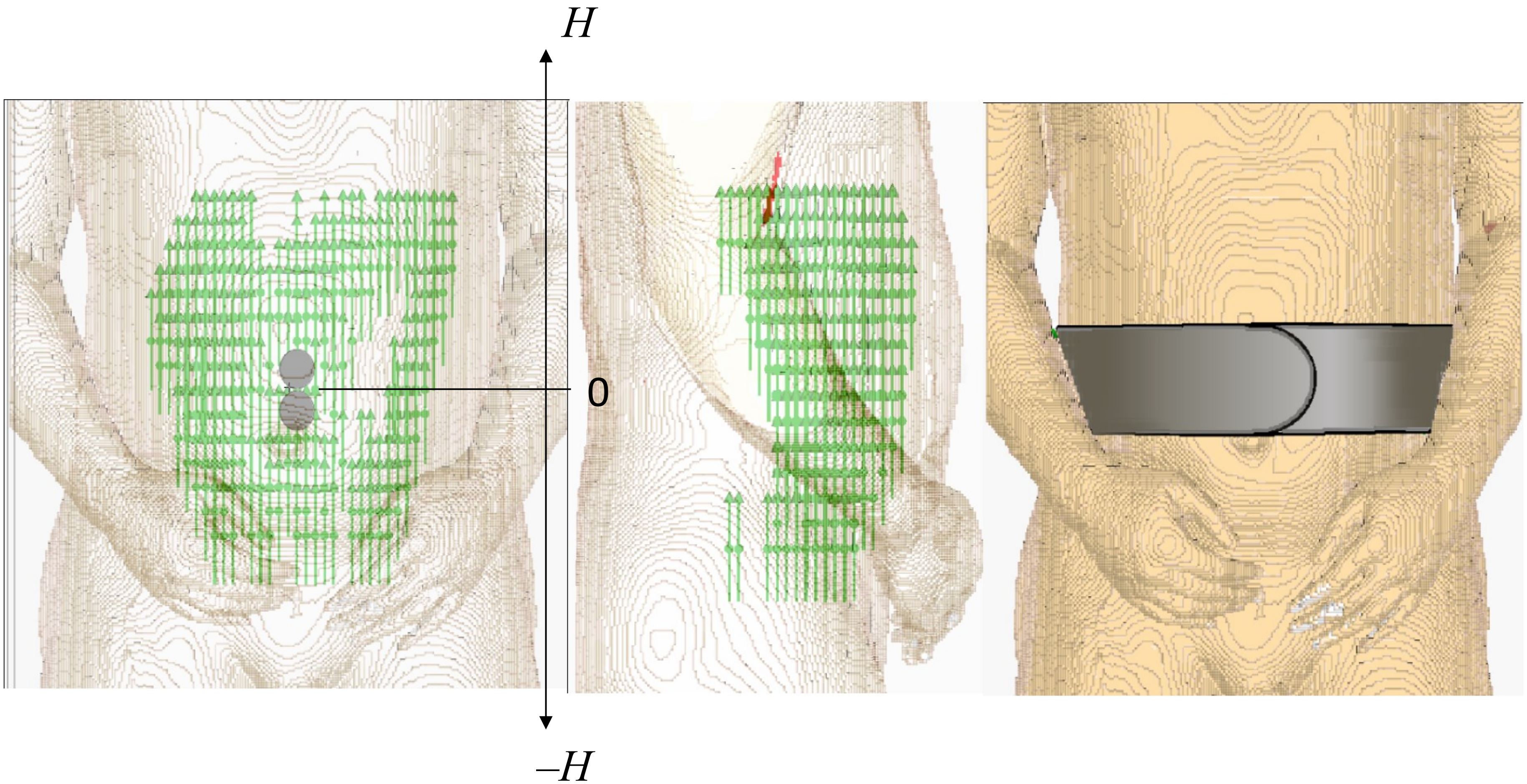


Basic idea for channel modeling

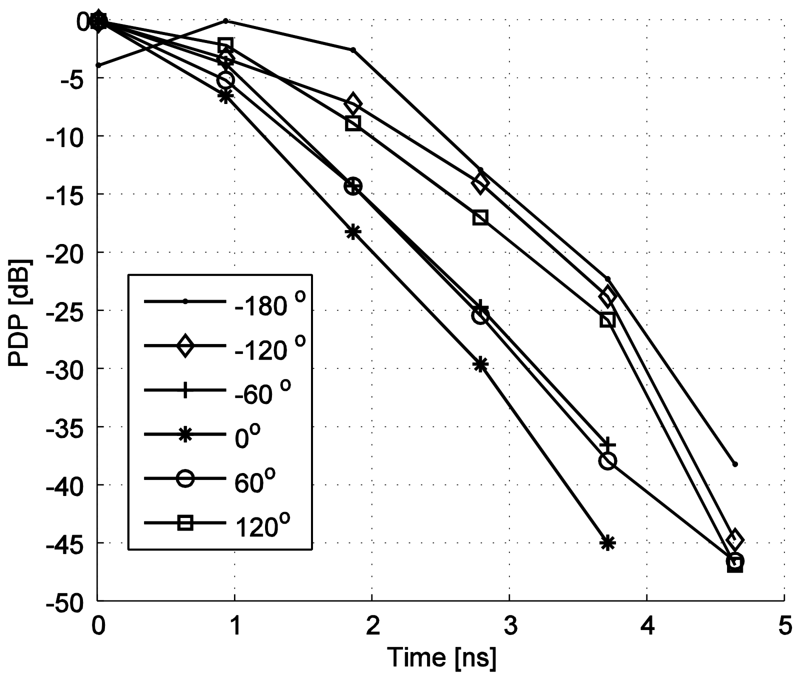


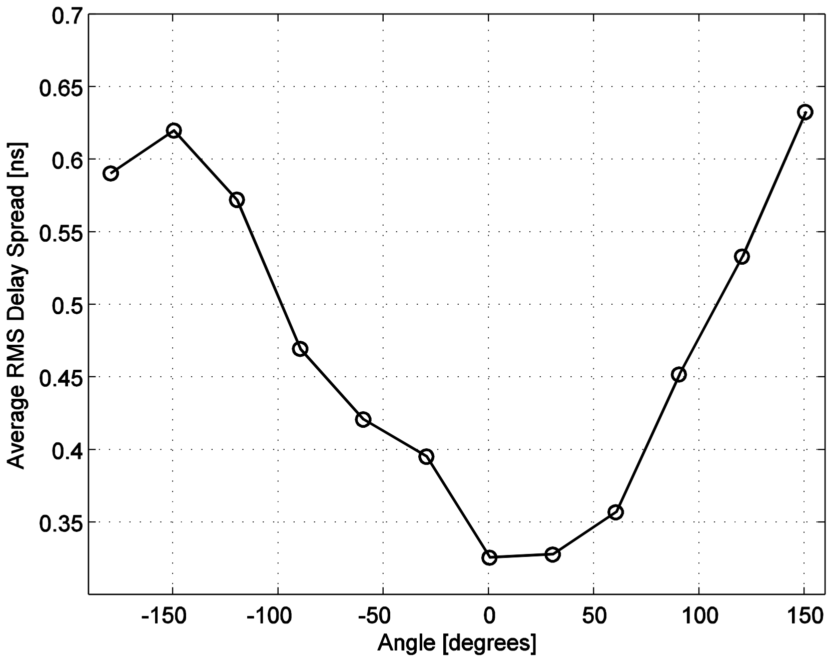


Electromagnetic simulation scenario (1)

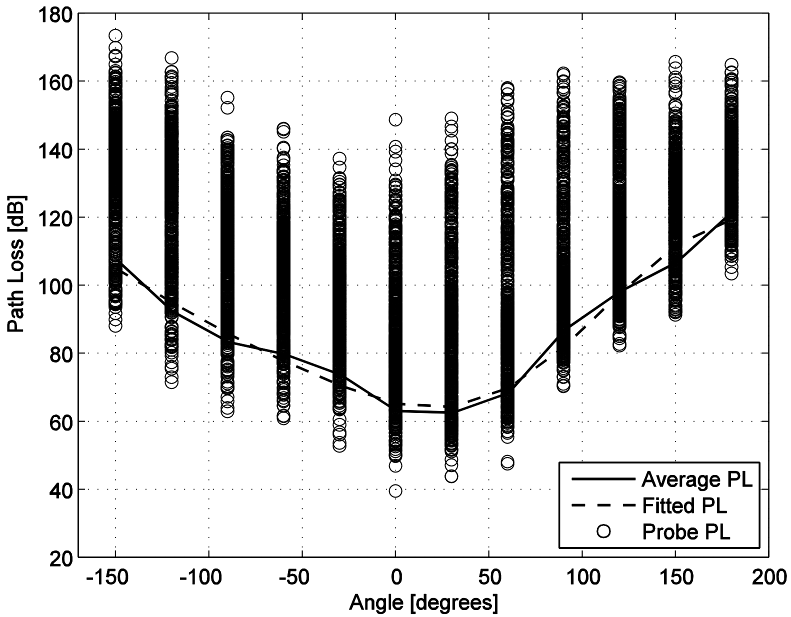


Results (1): Power delay profile and RMS delay





Model (1): Path loss as a function of θ

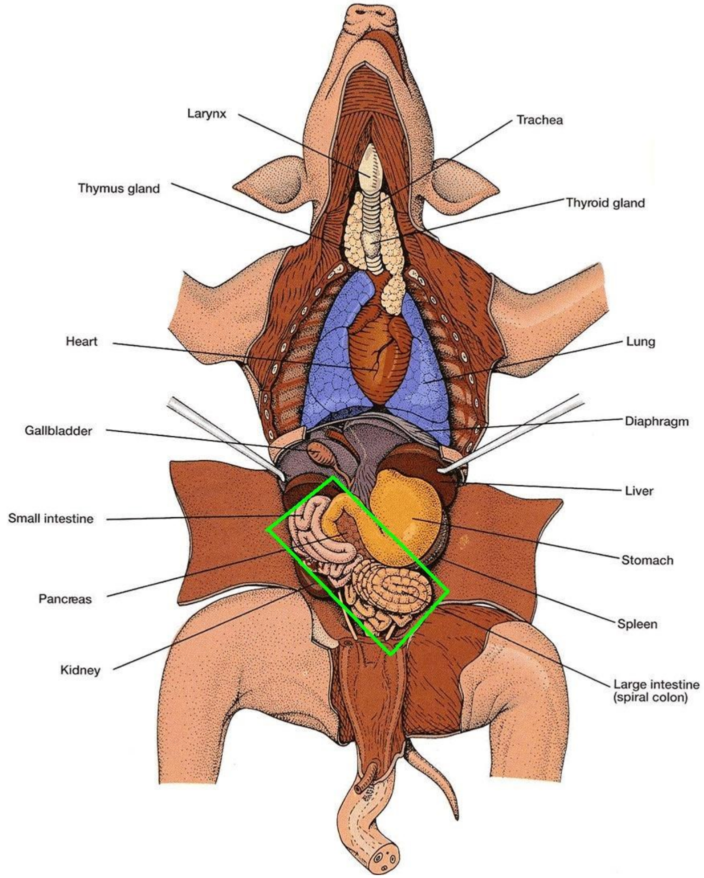


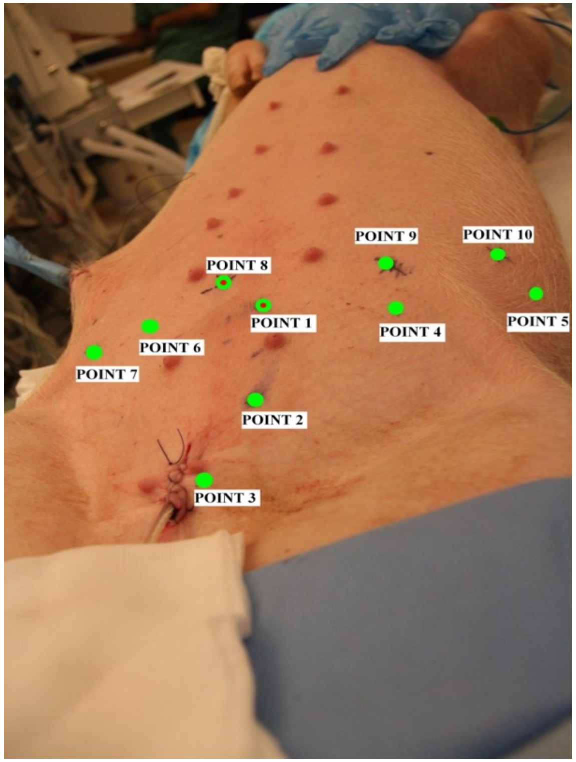
- p, scaling constant
- a, b, vectors with path loss fitting coefficients
- $\mathcal{N}$, a normal distributed random variable with mean μ and standard deviation σ

$$L(\theta)_{[dB]} = a_0 + \left[\sum_{i=1}^{I} a_i \times \cos\left(\frac{i\pi\theta}{p}\right) + b_i \times \sin\left(\frac{i\pi\theta}{p}\right) \right] + \mathcal{N}(\mu(\theta), \sigma(\theta))$$

In vivo Experiment

- Performed on three porcine subjects. Tx antenna placed within green borders

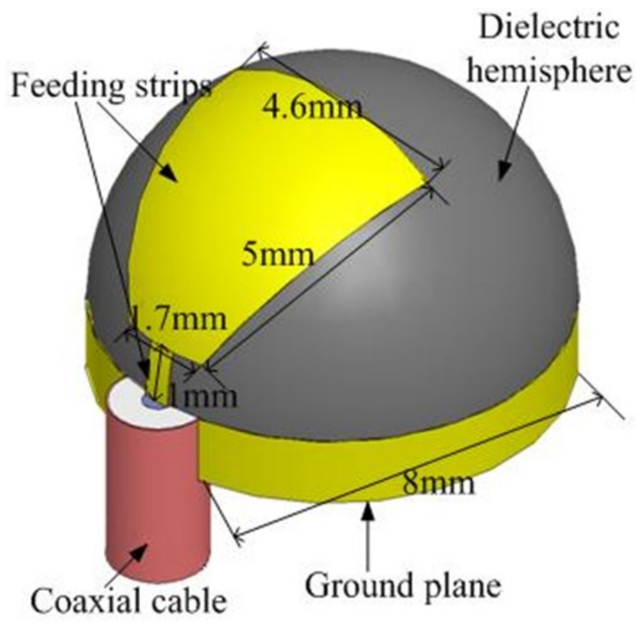




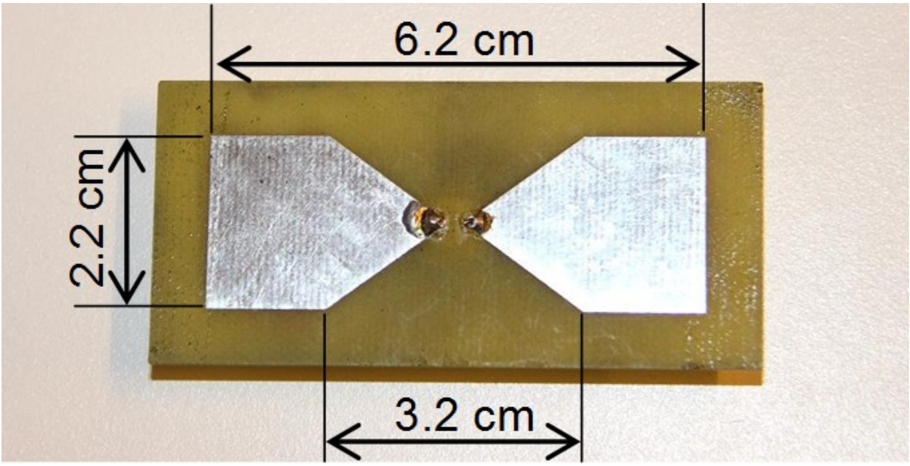
Experiment cont'd

- S-parameters measured with VNA

- Transmitter and receiver antennas:

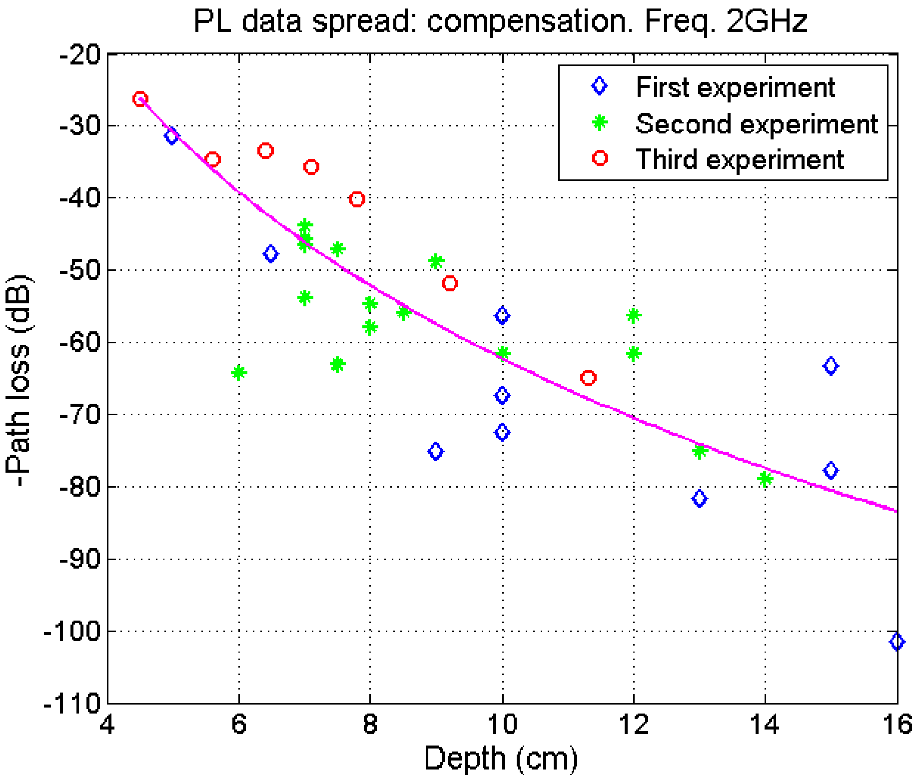


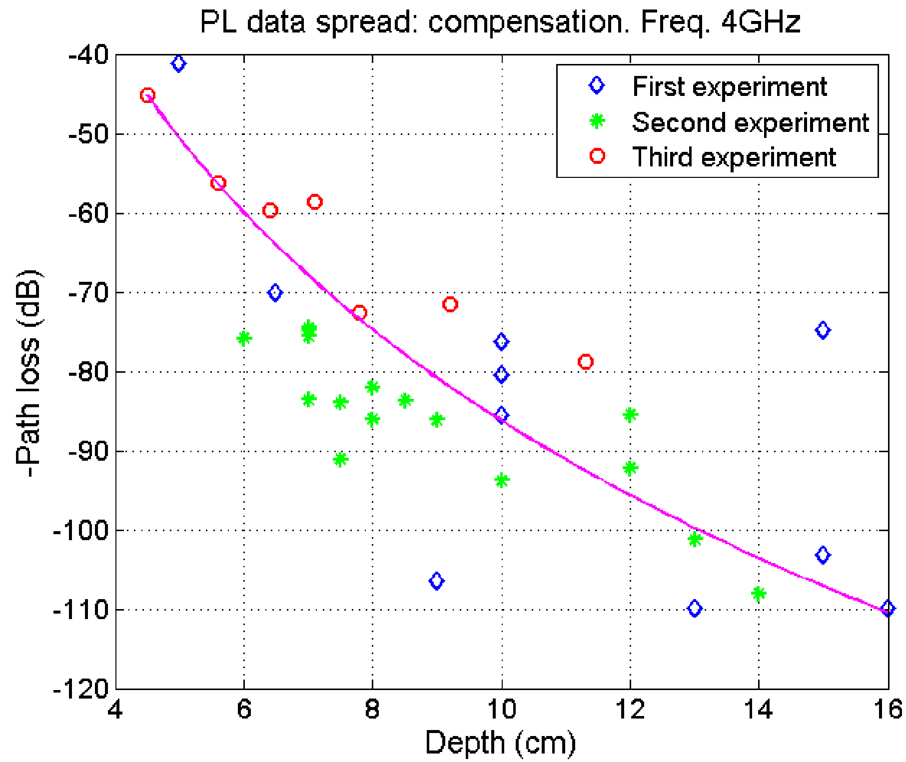
in body



on body

Path-loss modelling

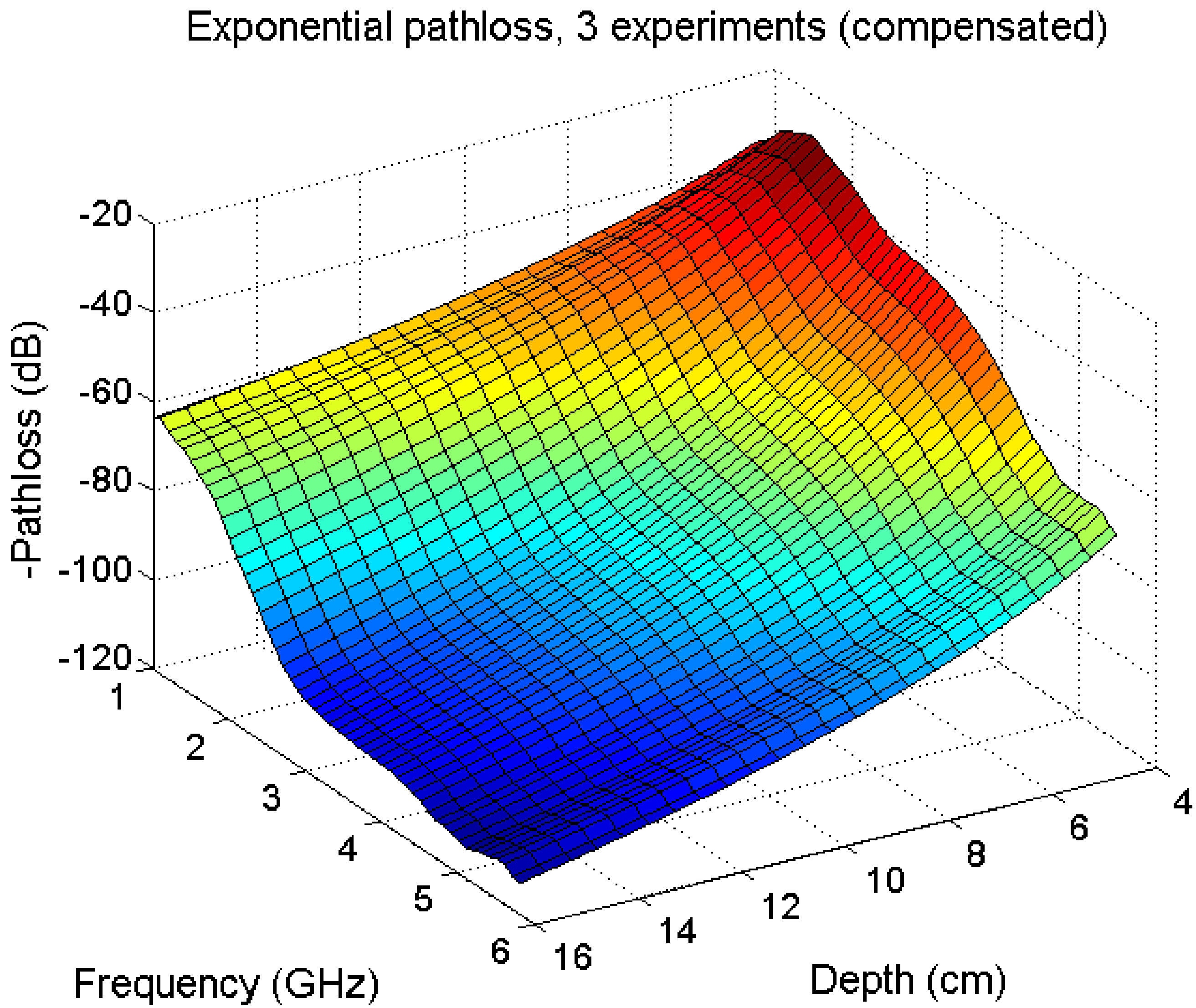




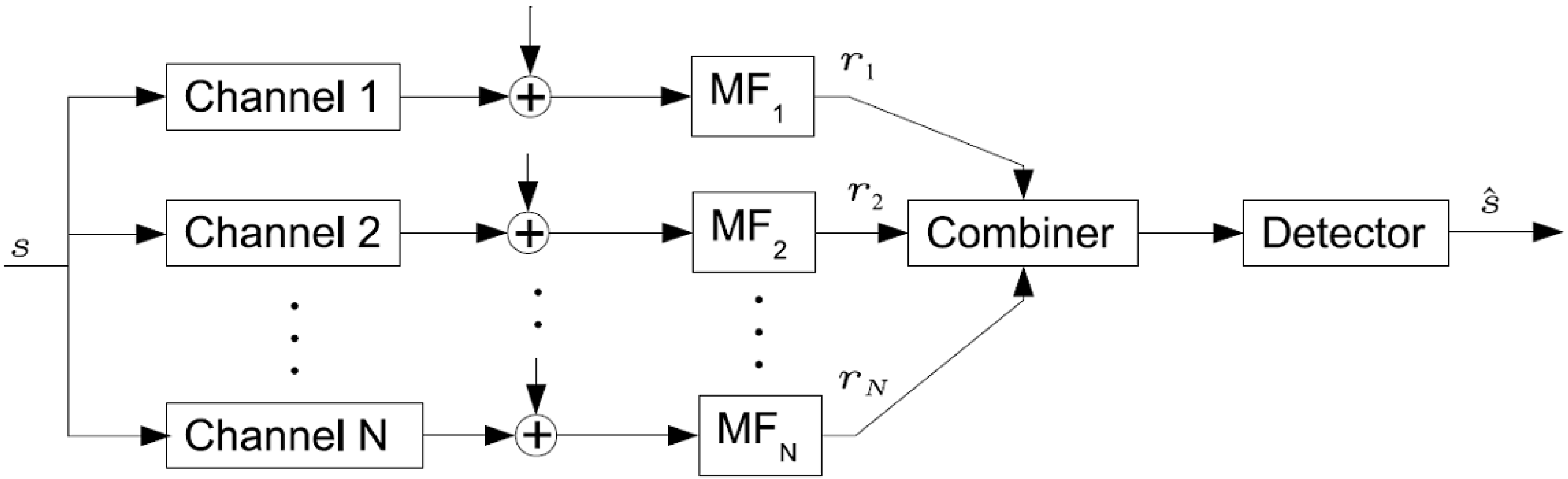
-A large spread in data. However, all experiments follow similar trend

-Curve shows best curvefitting (average response)

Path-loss model



Combining multiple antennas

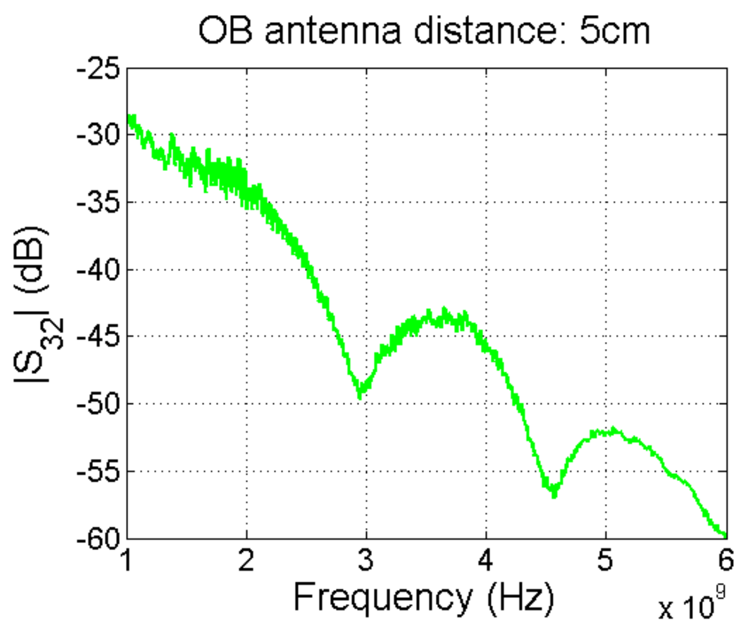


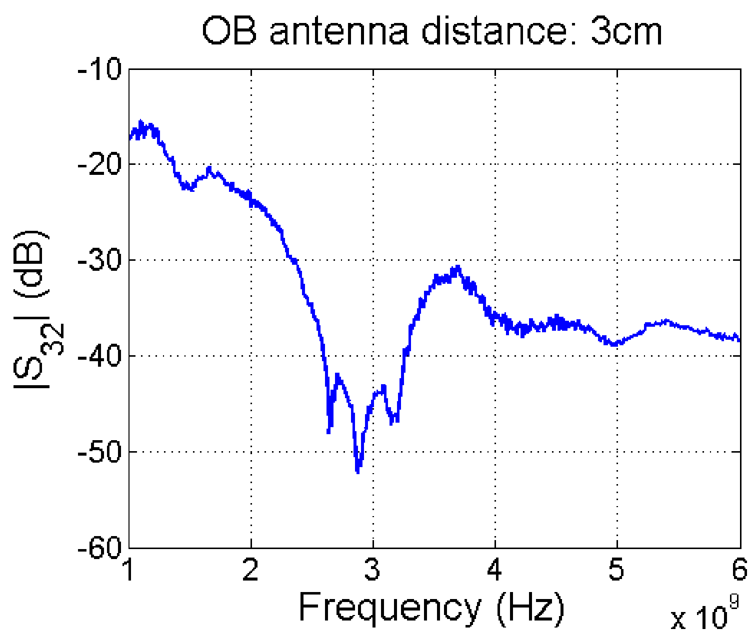
- Multiple receiver antennas should be applied
- Have correlated channels with shadowing.
- Determine from experiment if gain with multiple antennas is possible on harsh medium

Experiment: multiple antennas

- Applied two receiving antennas on the porcine subject simultaneously at distances 8, 5 and 3 cm

- Mutual coupling was acceptaly low in all cases





Multiple antennas cont'd

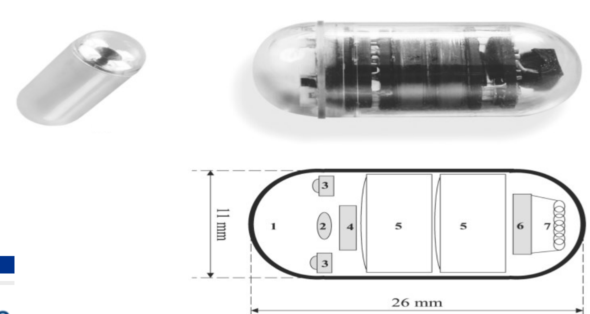
- **Result:**

Distance: 8 cm	Distance: 5 cm	Distance: 3 cm
0.18 dB (P1P6)	1.23 dB (P1P5E2)	2.09 dB (P9P12E2)
0.16 dB (P1P4E2)	0.22 dB (P1P6E2)	1.1 dB (P1P7E2)
0.34 dB (P8P9)	1.67 dB (P15P16E2)	1.98 dB (P1P8E2)

- **Gain is indeed possible. With more than 2 antennas gains in the order of atleast 6-7dB could be achieved.**

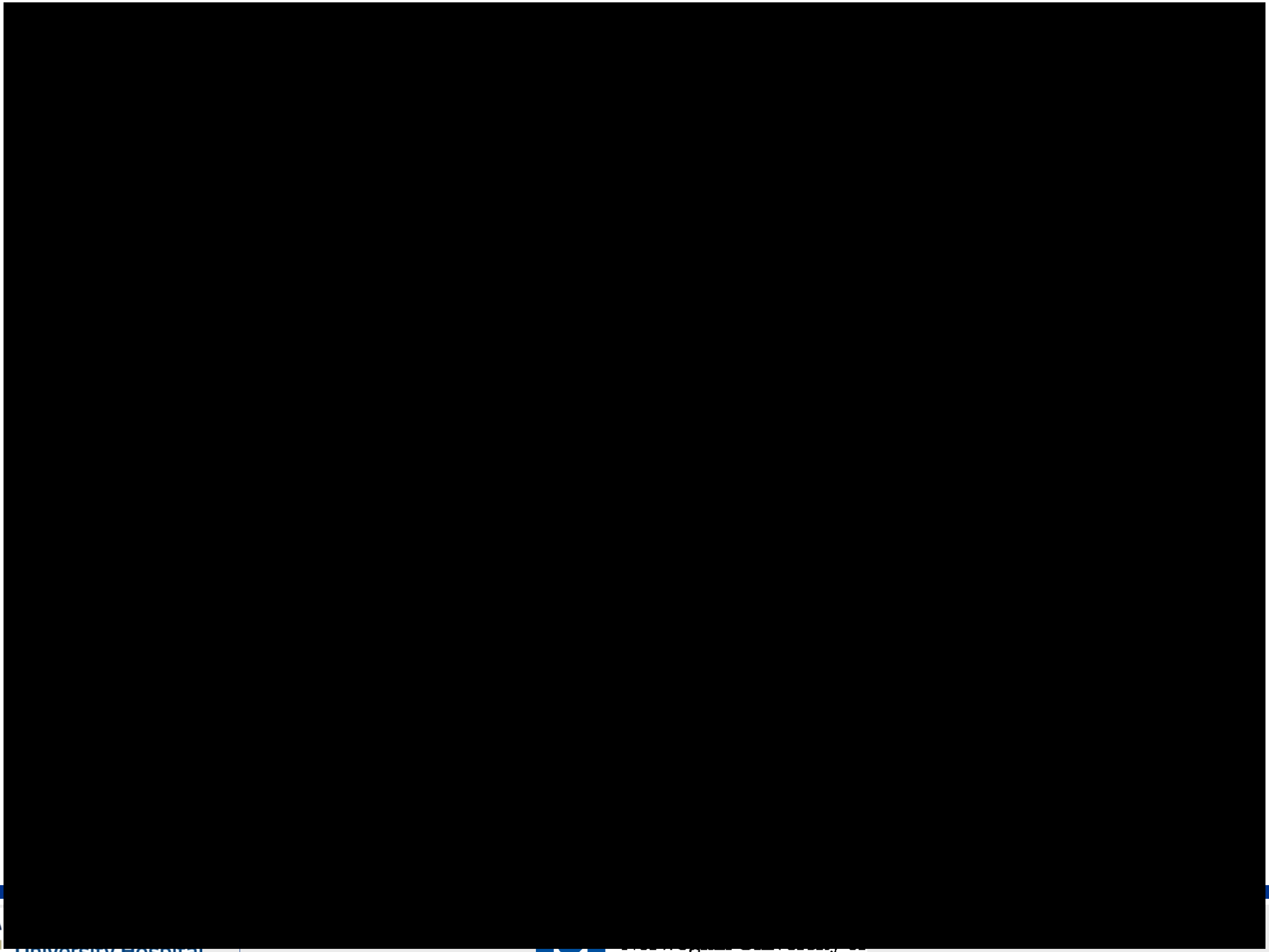
Comparison:

Size: 11 × 26 mm	**Size: less than 11 × 26 mm**
Transmission frequency: 402–405 MHz	**Transmission frequency: 1063–3841 MHz**
Bandwidth: 300 kHz	**Bandwidth: at least 500 MHz**
Data Rate: 800 kbps	**Data Rate: 80 Mbps**
Image Rate: 2 to 10 fps	**Image Rate: 30 fps**
Image Resolution: 256 × 256 pixels	**Image Resolution: 1920 × 1080 pixels**
Power consumption: ~100 mW	**Power consumption: estimated 1 mW**
Operating life: 8 hours	**Operating life: more than 8 hours**



Possibility of smaller batteries
Possibility of remote control

Wireless Full HD Video Trasmission

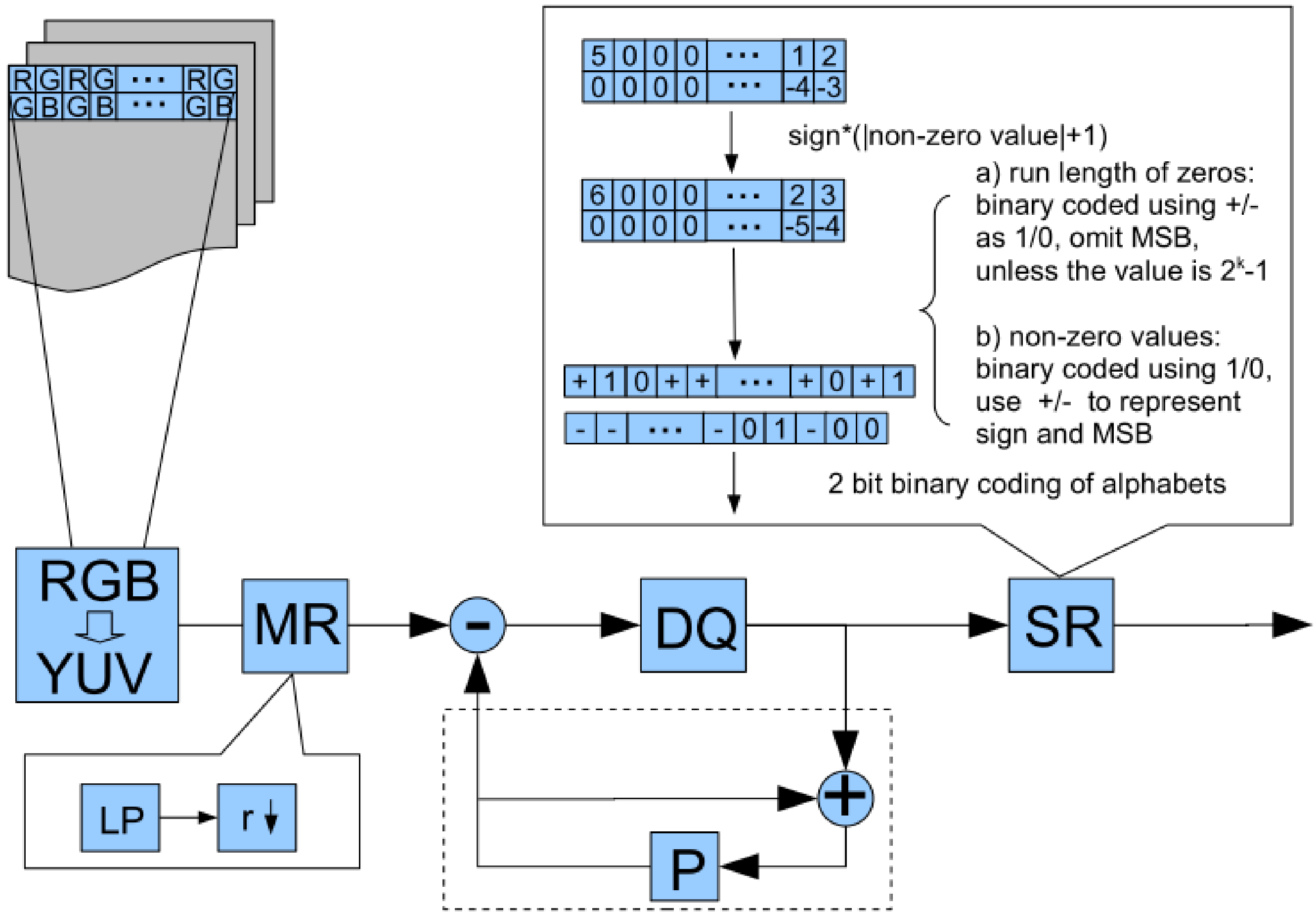


Part 2: Very Low Complexity and Low Rate Image Coding for the Wireless Endoscope

Design Goals and Constraints

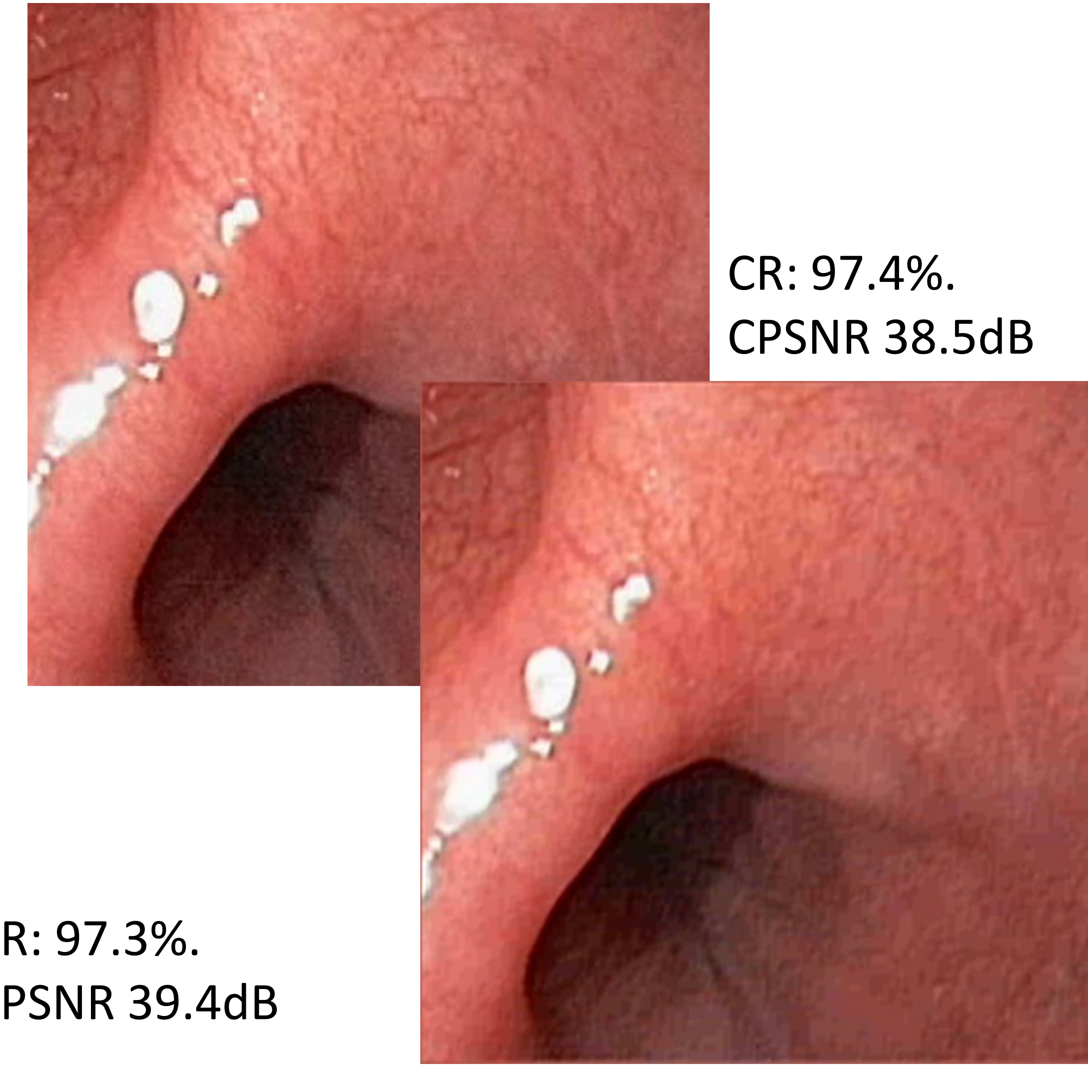
- Low rate low power video coding.
- Main constraints in terms of available power and physical size.
- A good compression algorithm should offer:
  - Satisfactory reconstructed image quality (35-40dB PSNR).
  - High compression ratio (>85%)
  - Uses little power for processing.
  - Does not require large memory storage.

System Architecture



Performance Evalution

CR: 97.3%.
CPSNR 39.4dB

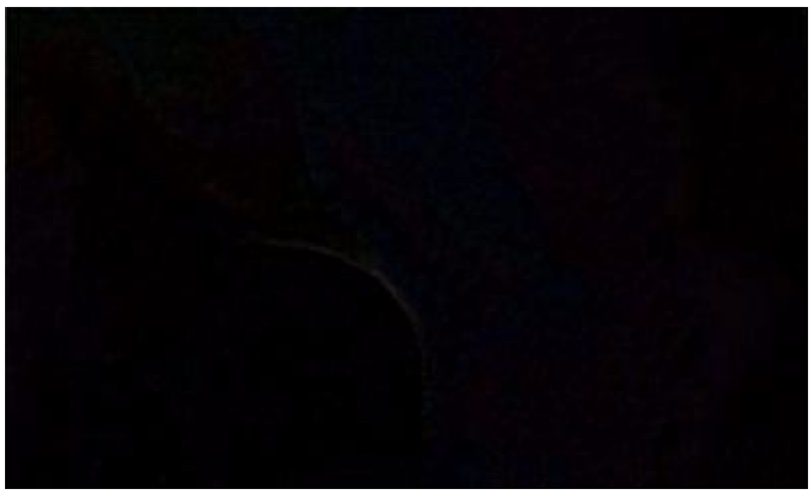


CR: 97.4%.
CPSNR 38.5dB

Video Examples - 1

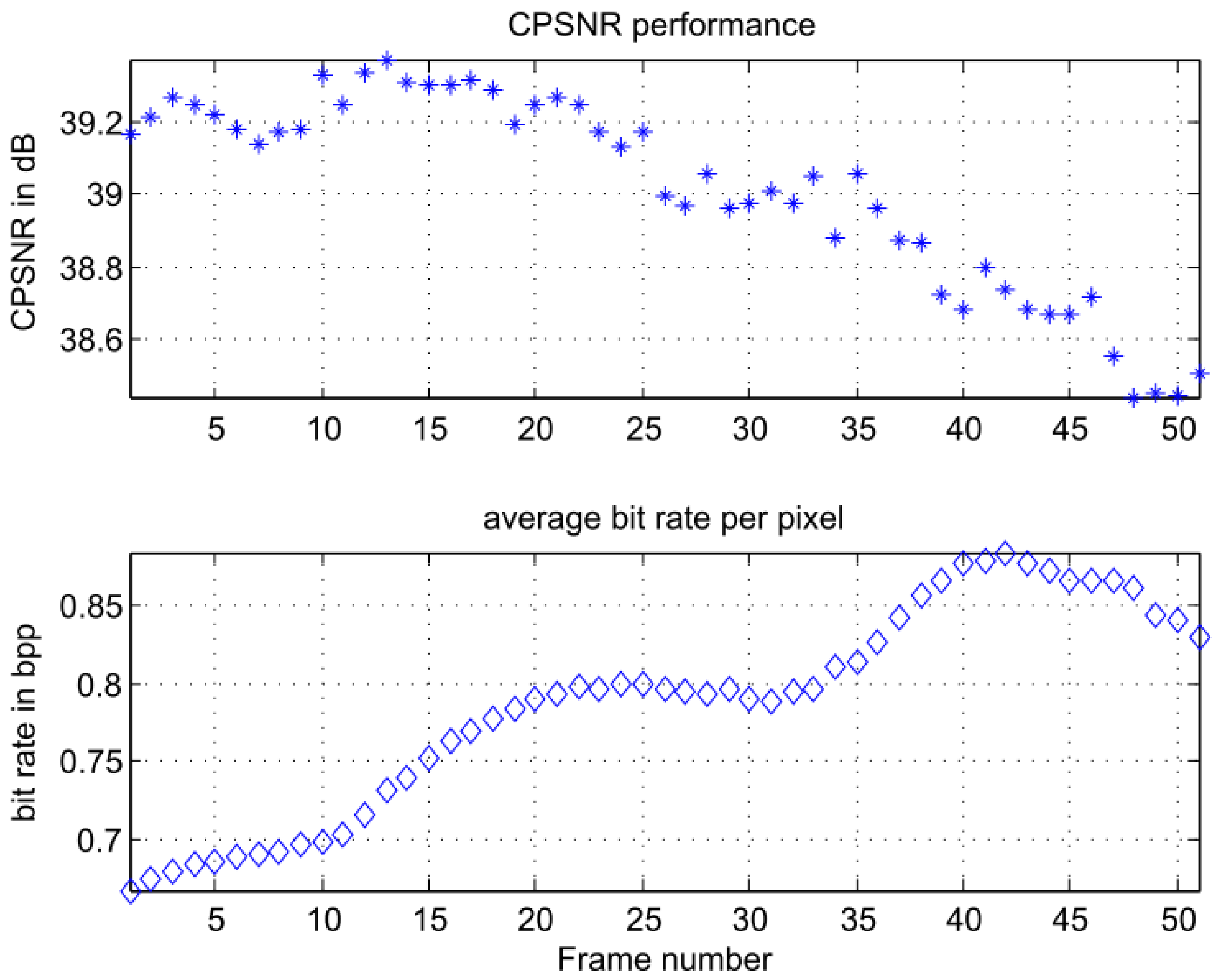
original

reconstruction from downsample rate 3

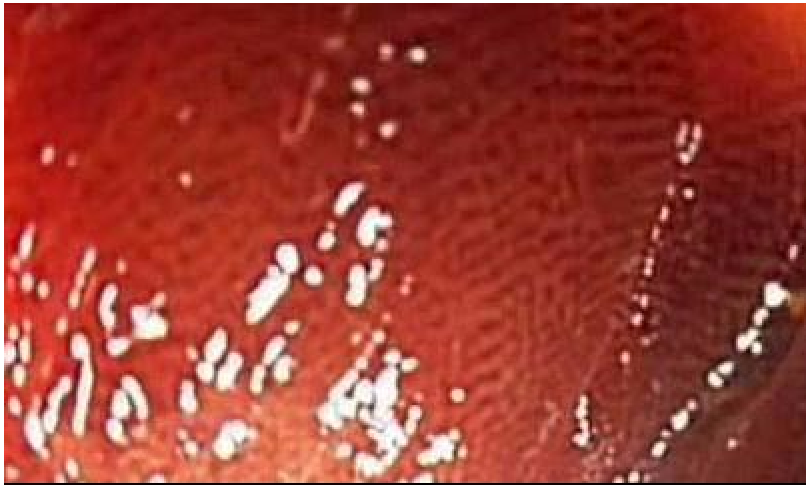


difference

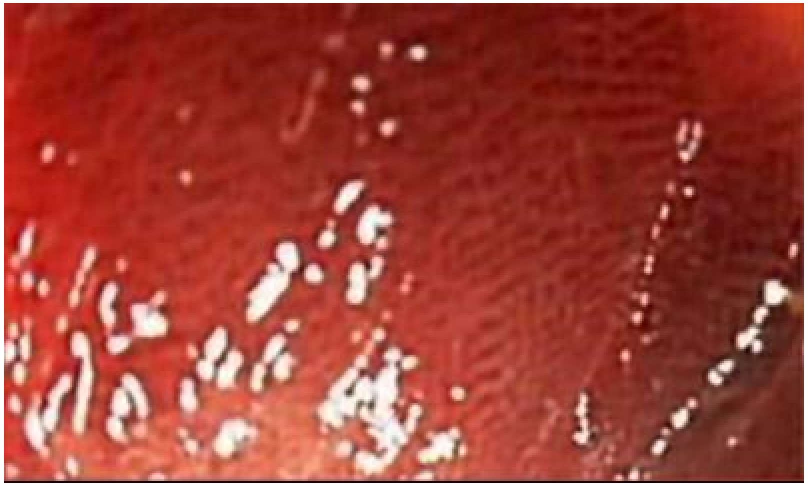
PSNR and Bit Rate Performance



Video Examples -2



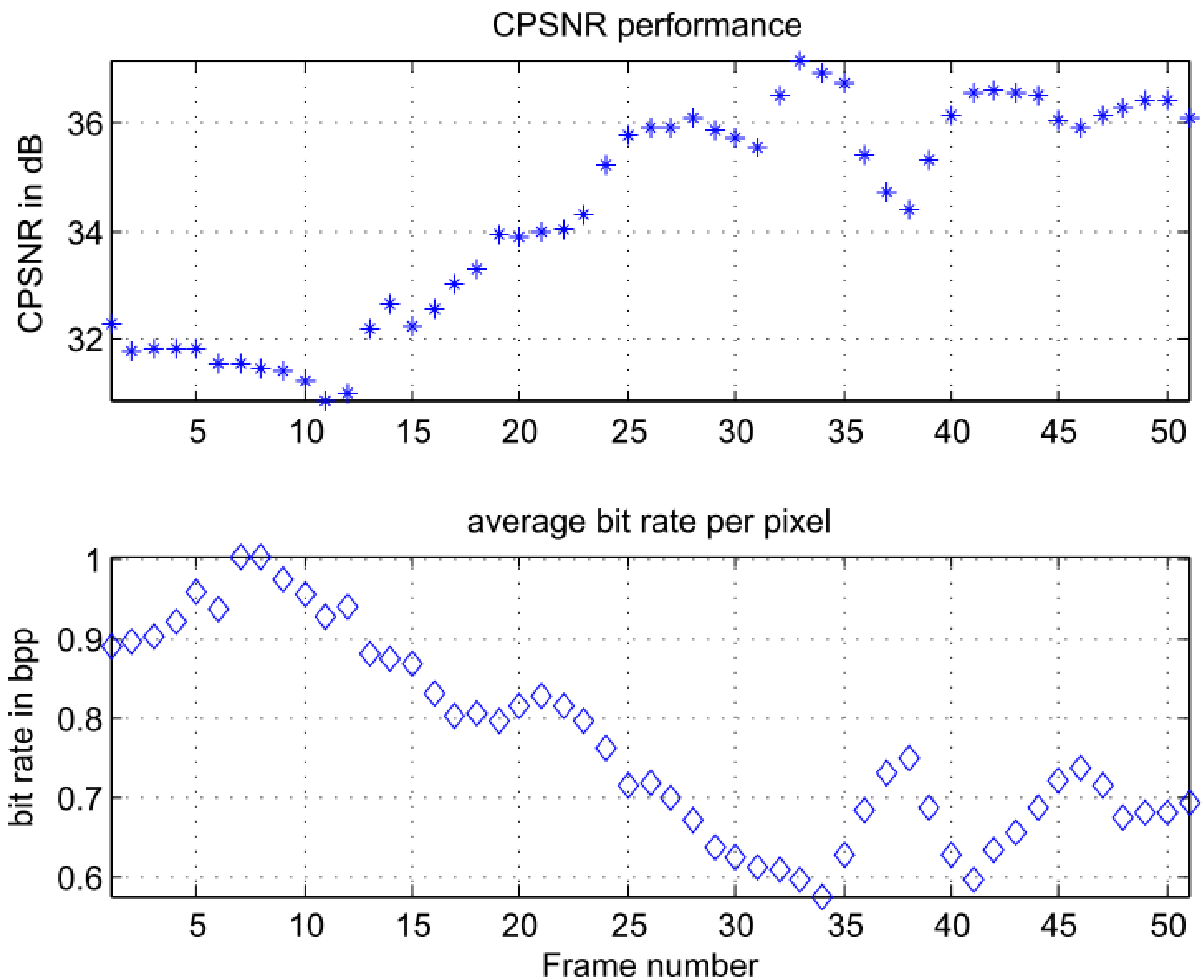
original



reconstruction from downsample rate 3

difference

PSNR and Bit Rate Performance



Part 3: Anomalies detection and viewing time reduction

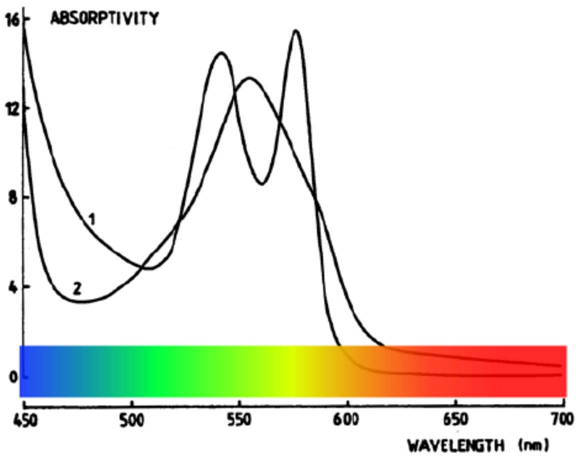
Problem

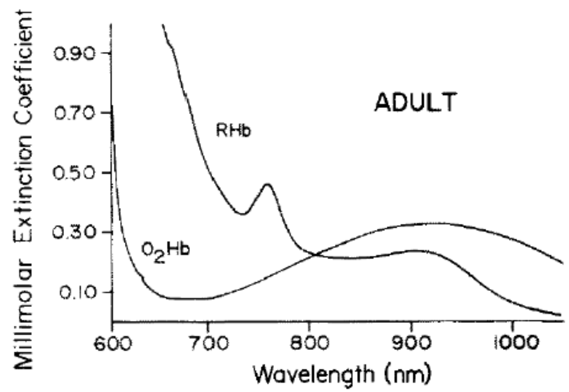
- To perform mass screening
  - capsule video contains only clinically "relevant" information to reduce the viewing time
  - important also the video contains location information for further reference
  - should be able to perform analysis on partly "contaminated" video sequences

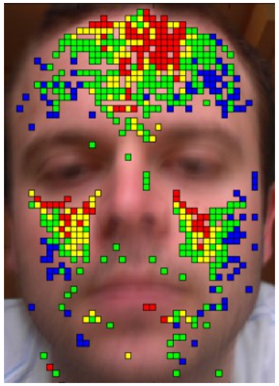
Anomalies

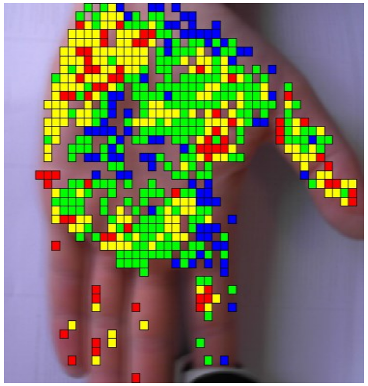
- Bleeding
- Polyps
- Cancer tissues

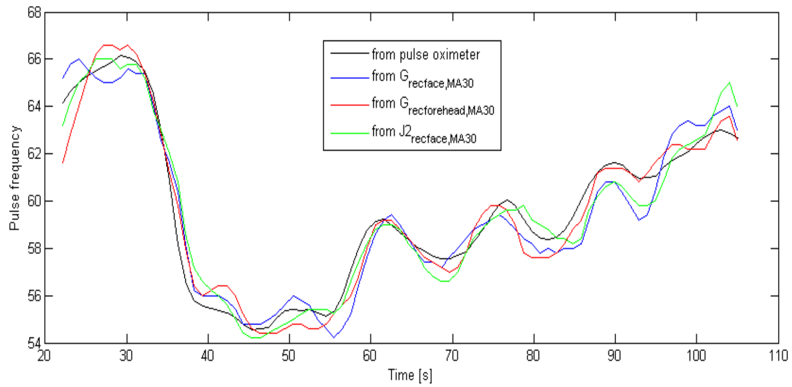
RGB Signals and Pathology



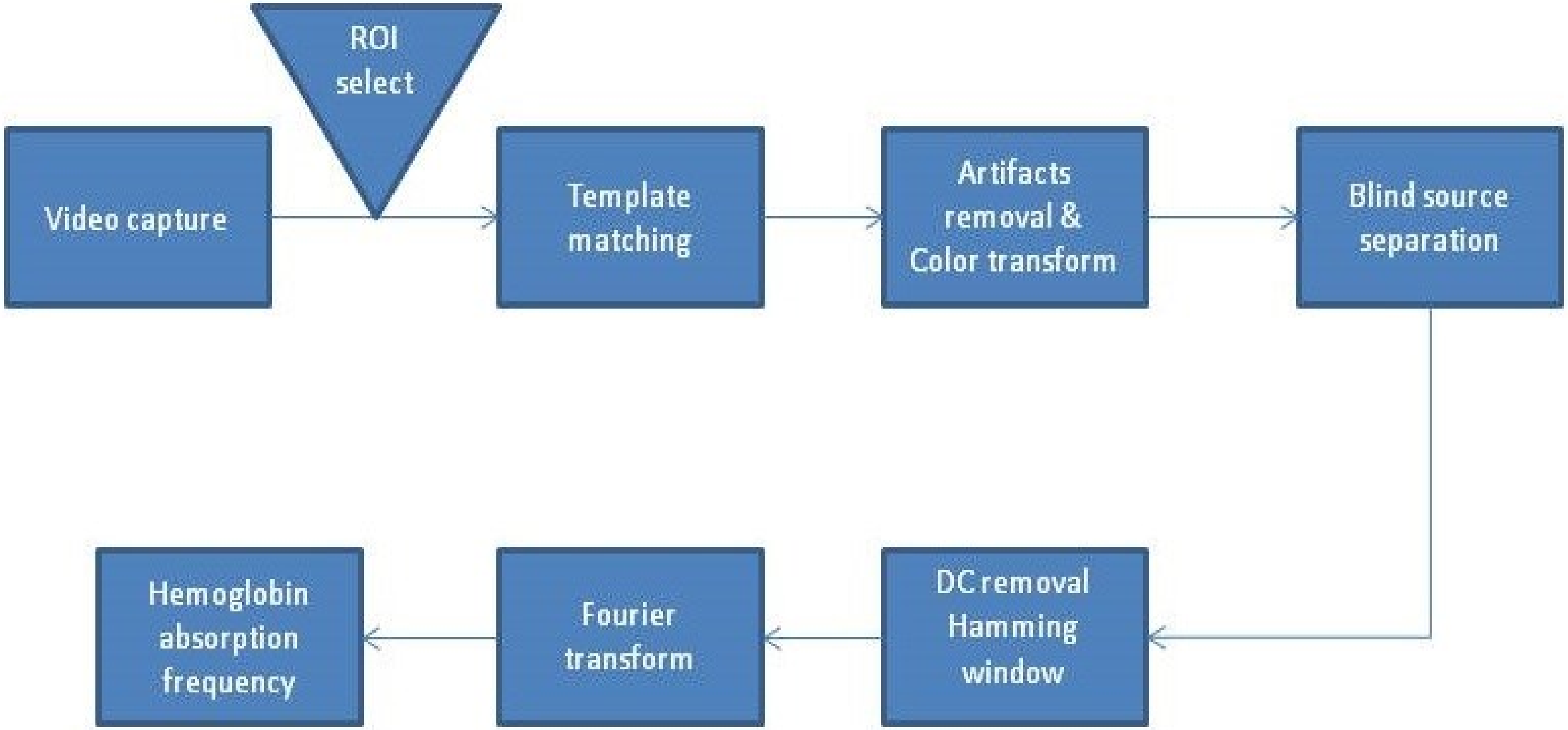




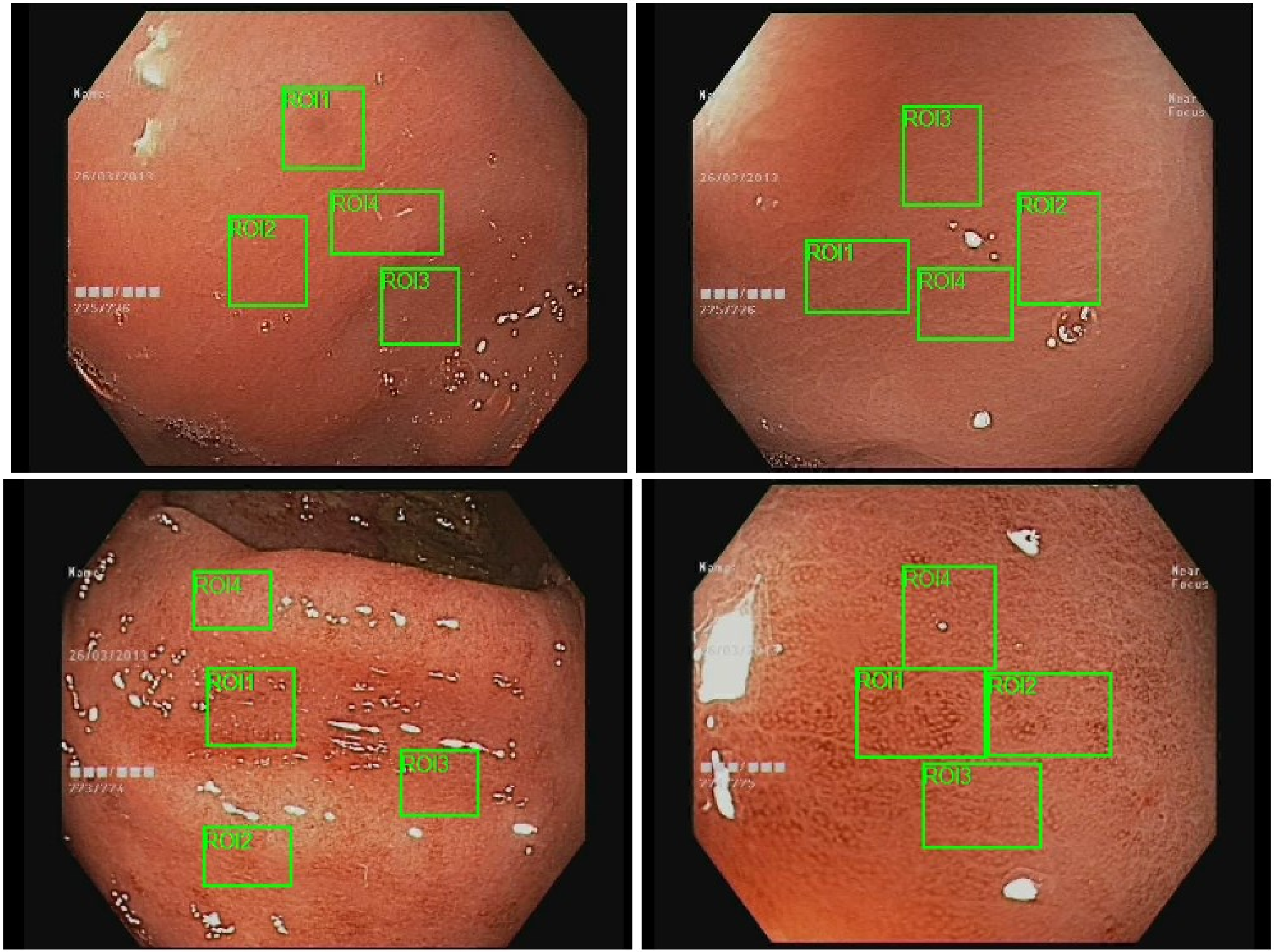




Detection of microcirculation



Example

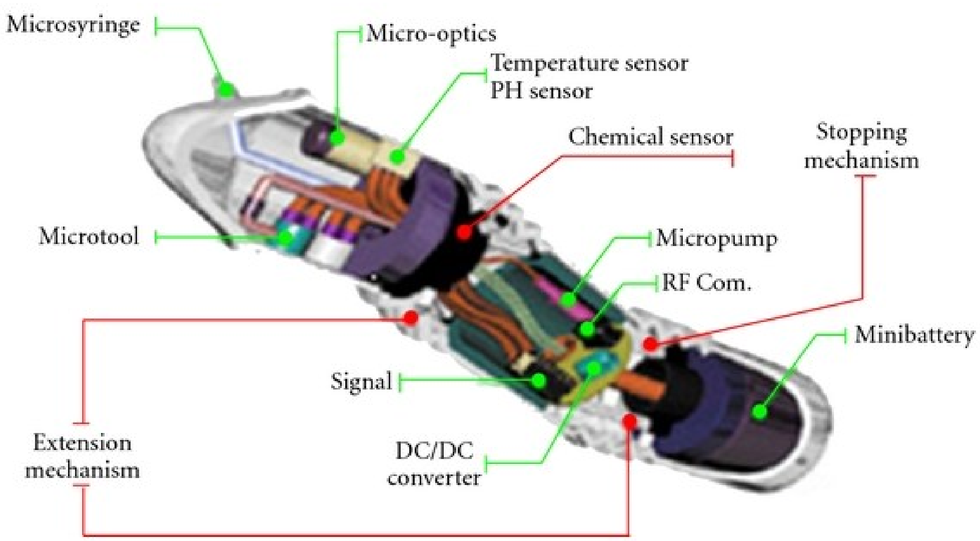


Healthy

Unhealthy

Future Electronic Pill

Requirements for visualization and therapeutic procedures



Typical Size: 11 × 26 mm

Data Rate: >> 2 Mbps

Image Rate: At least 30 fps

Image Resolution: >> 1920 × 1080 pixels

Transmission frequency: > 1 GHz

Bandwidth: At least 20 MHz

Power consumption: At least 300 mW*

Operating life: > 8 hours

Wireless power transmission

Robotic locomotion mechanism

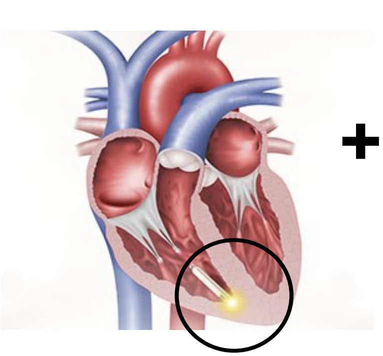
Magnetic control

EM/tomographical images

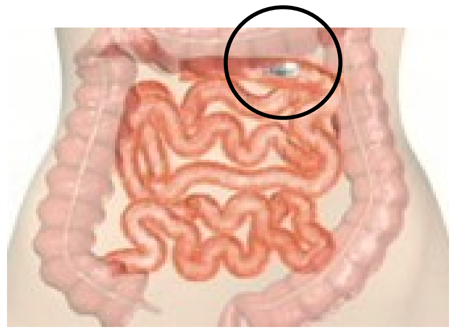
HORIZON 2020 PROJECTS

Wireless In-Body Environment 2016 – 2019

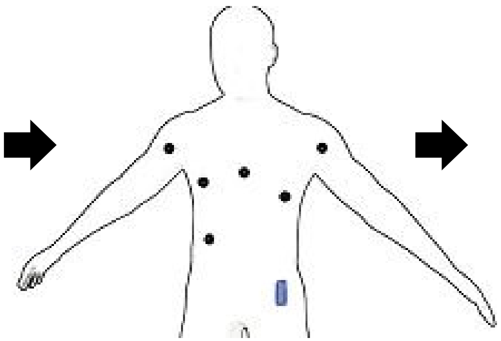
MARIE SKŁODOWSKA-CURIE ACTIONS:ITN:2015



Leadless Pacemaker



GI WCE



Body Sensor Network

Handheld Monitor

The project will study novel implantable sensors with wireless communication and power transfer interfaces for heart and gastrointestinal (GI) tract. The applications will be monitor and pacing the heart for resynchronization and detecting bleeding/cancer tissues in the GI tract. There will be ***16 PhD fellows***.

Partners: NTNU, Oslo University Hospital, SORIN Group France, ValoTec France, Technical University of Dresden Germany, Ovesco AG Germany, Universitat Politècnica de València Spain, and La Fe Hospital Spain.

MACQUARIE University

NTNU
Norwegian University of Science and Technology

Norwegian University of Science and Technology and Macquarie University

Joint PhD Project Opportunity

“Modeling and Utilizing the Nervous System for Stimulation and Intra-body Communications”