Providing Endoscopic Orientation

using a Multi-Sensor approach

March 18^{th}, 2009

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2 Time-of-Flight (ToF) Endoscopy
3 MEMS based Endoscopic IMU
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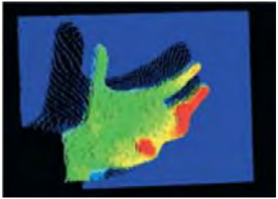
5 Outlook



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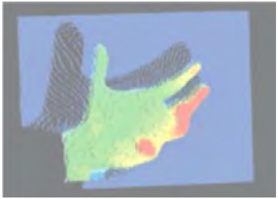


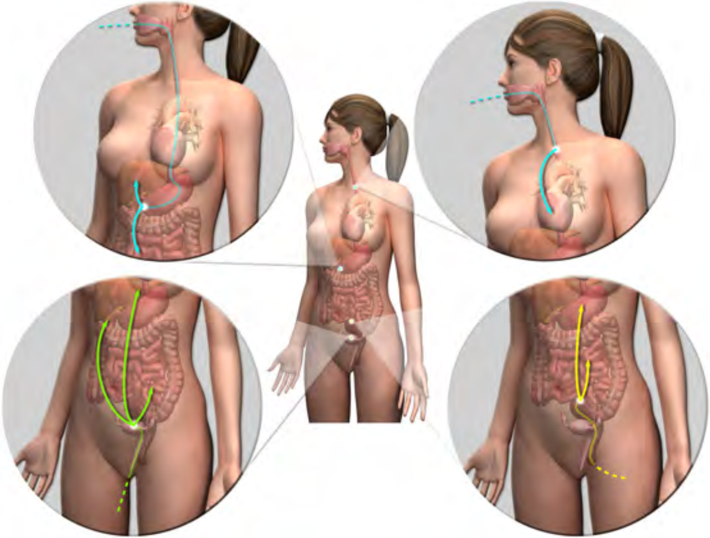
Participating groups with NOTES

Great chance for technical innovations

Figure: Interdisciplinarity of NOTES

Routes through natural orifices

Natural Orifice Translumenal Endoscopic Surgery



Potential barriers to clinical practice

According to the NOTES white paper, New York 2005

Fundamental challenges to the safe introduction of NOTES

- Access to peritoneal cavity
- Gastric or intestinal closure
- Prevention of infection
- Development of suturing and anastomotic (nonsuturing) devices
- Maintaining spatial orientation
- Development of a multitasking platform
- Management of intraperitoneal complications and hemorrhage
- Physiologic untoward events
- Training other providers

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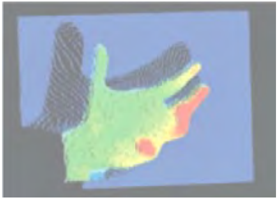


State of the Art: PMDvision 3kS

Time-of-Flight (ToF) technology

- Lateral resolution: 64$\times$48 pixel
- Depth resolution: 3 mm
- Wavelength: 870 nm
- Pixel dimension: $40\mu m \times 40\mu m$
- Modulation frequency: $20 - 30MHz$ ($\Rightarrow \lambda = 15 - 10m$)
- Frame rate: >15 fps

Figure: ToF-camera and example images

March 1^{st}, 2009: PMDvision Cam Cube

Time-of-Flight (ToF) technology

- Lateral resolution: 204×204 pixel
- Depth resolution: 3 mm
- Wavelength: 870 nm
- Pixel dimension: $40\mu m \times 40\mu m$
- Modulation frequency: $20 - 40MHz$ ($\Rightarrow \lambda = 15 - 7.5m$)
- Frame rate: >15 fps

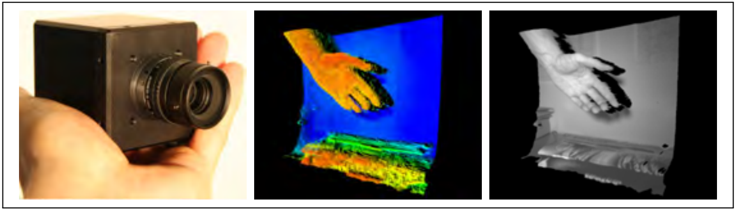
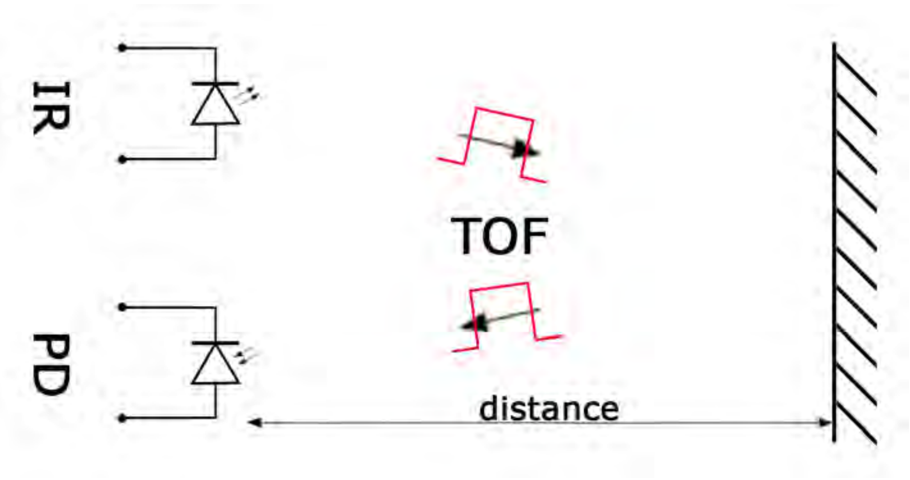


Figure: ToF-camera and example images

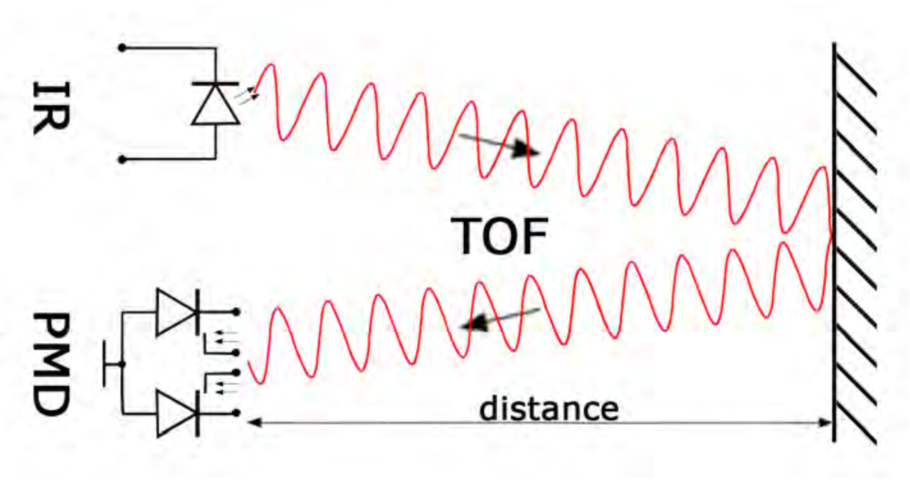
Time-of-flight principle

Pulsed modulation



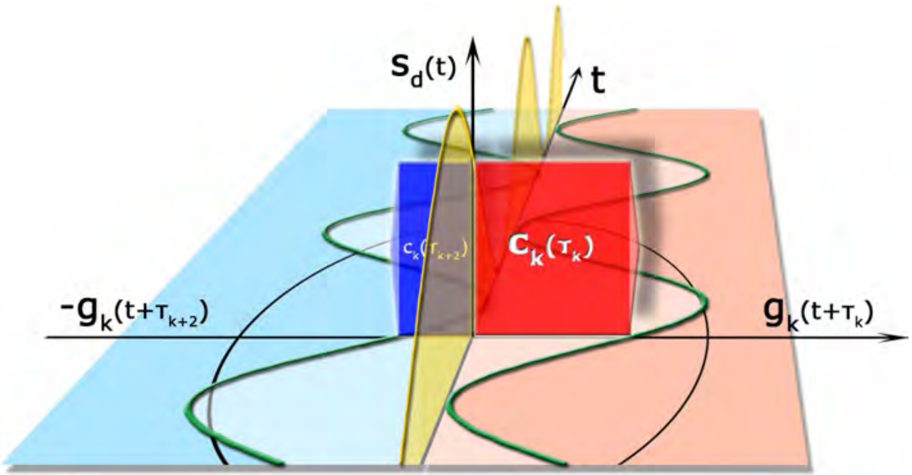
Time-of-flight principle

Continuous wave modulation



"Ladungsschaukel"

charging swing



ToF accuracy

Illumination requirements

- small light emitting surface
- high power
- fast modulation
- narrow-band for ambient light suppression

$$\text{accuracy} \sim \frac{c}{2f_{mod}} \cdot \sqrt{\frac{P_{mod} + P_{amb}}{P_{mod}^2} \frac{A}{k_{opt} q_e r T}}$$

c :	relative speed of light	k_{opt} :	optical system constant
f_{mod} :	modulation frequency	q_e :	quantum efficiency
P_{laser} :	power of modulated signal	r :	target reflectivity
P_{amb} :	ambient light power	T :	integration time
A :	illuminated area		

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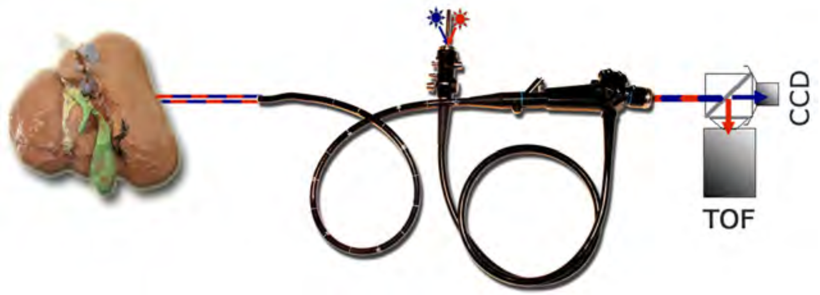
Idea of MUSTOF

Parallel acquisition with ToF camera and CCD camera

Parallel acquisition of depth and image data combining a ToF and a CCD chip:
Multi-Sensor-Time-Of-Flight (MUSTOF) endoscope



Navigation support - Orientation

Finding the entry point to the peritoneal cavity

Challenge:

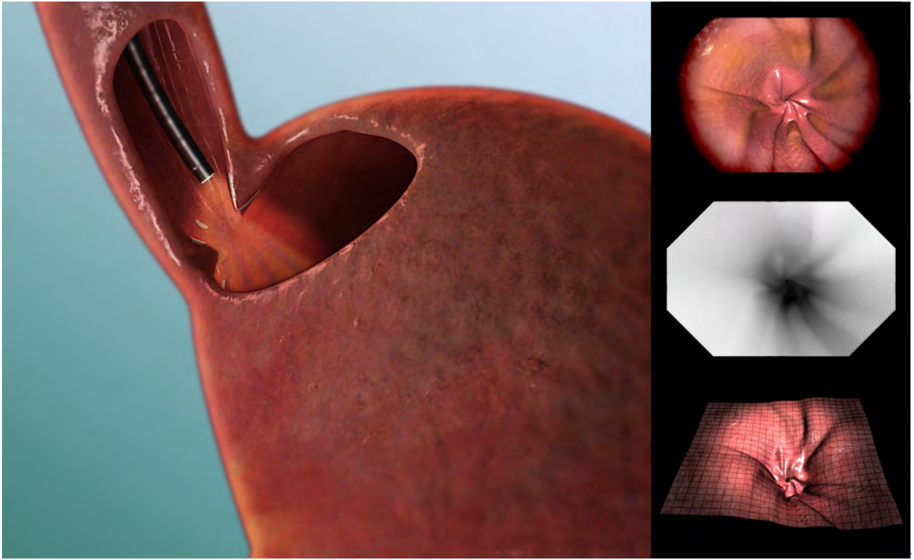
- More information on position and orientation of the robotic device or the endoscope

Solution:

- Nonrigid registration of intraoperative 3-D data with preoperative CT or MR data is possible
- Calculated transformation parameters can be used to represent, correct und visualize actual position and orientation

Navigation support - Orientation

Finding the entry point to the peritoneal cavity



Navigation support - Augmented Reality

Finding the entry point to the peritoneal cavity

Challenge:

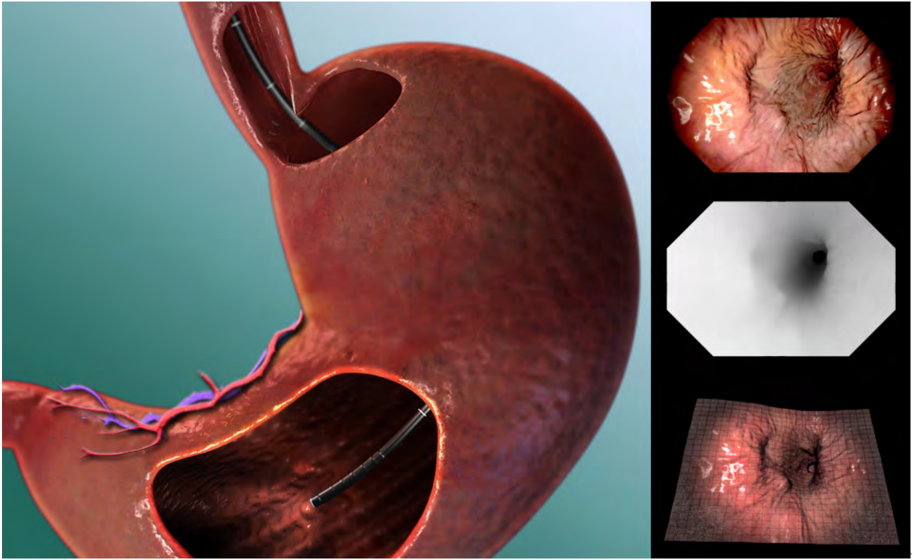
- Avoid injuries of hidden organs and vessels, e.g. while finding the entry point to the peritoneal cavity
- Knowledge of structures behind the visible wall is needed for a safe incision

Solution:

- Registration with preoperative volumes
- Segmentation of objects of interest in the preoperative volumes
- Adaption of those objects by iteratively computed transformation parameters
- Visualization of hidden organs or vessels in intraoperative endoscopic images by augmented reality

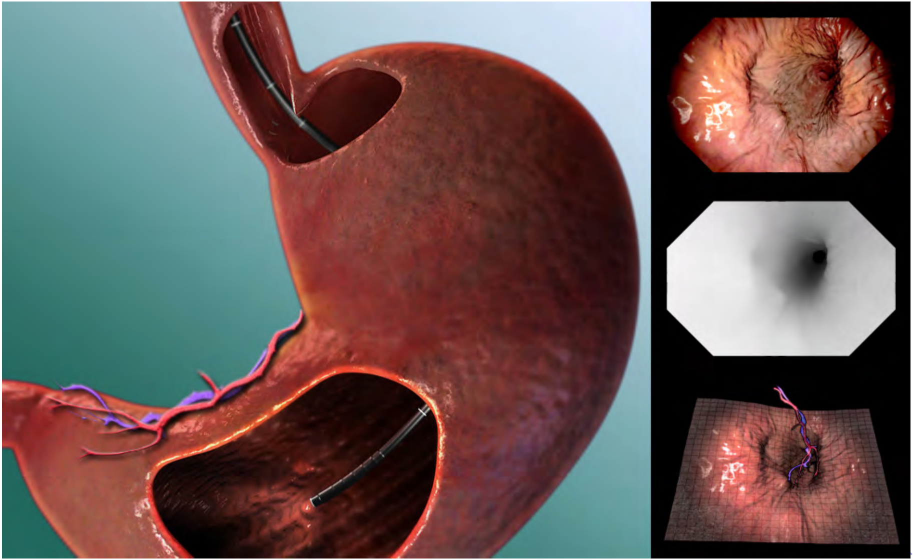
Navigation support - Augmented Reality

Finding the entry point to the peritoneal cavity



Navigation support - Augmented Reality

Finding the entry point to the peritoneal cavity



Navigation support - Off-axis view

Finding the entry point to the peritoneal cavity

Challenge:

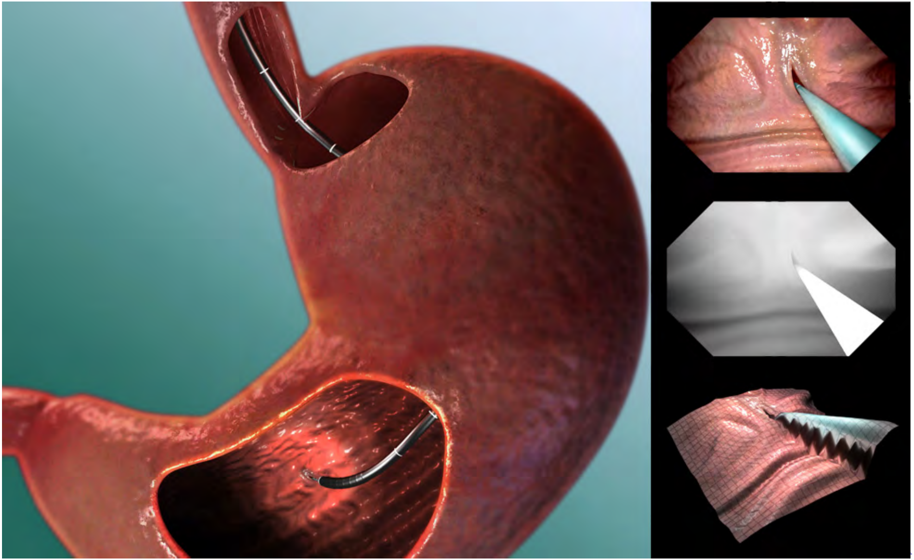
- Overcome boundaries of limited field of view like axis in-line view and loss of spatial orientation

Solution:

- 3-D surface knowledge can be used to extend and virtually rotate the field of view
- With a 3-D mosaicking technique, the field of view can be extended by reconstruction of the operation area.

Navigation support - Off-axis view

Finding the entry point to the peritoneal cavity



Navigation support - Collision prevention

Finding the entry point to the peritoneal cavity

Challenge:

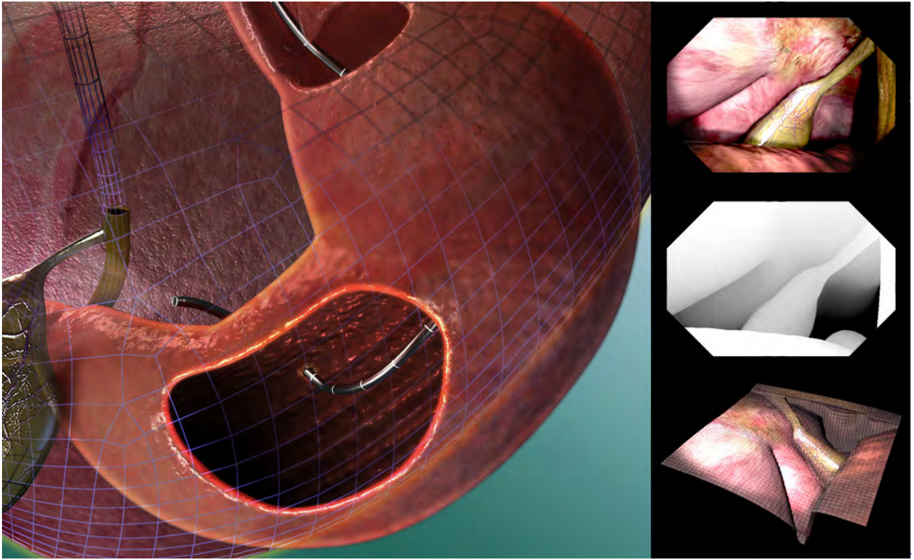
- Provide a higher grade of safety for automatic tools and robotic devices
- Especially important with multiple instruments through only one flexible endoscope

Solution:

- With real-time distance information efficient collision prevention with tissue or other instruments can be enabled
- Auto-positioning depending on respiration or other patient movements will be very helpful.

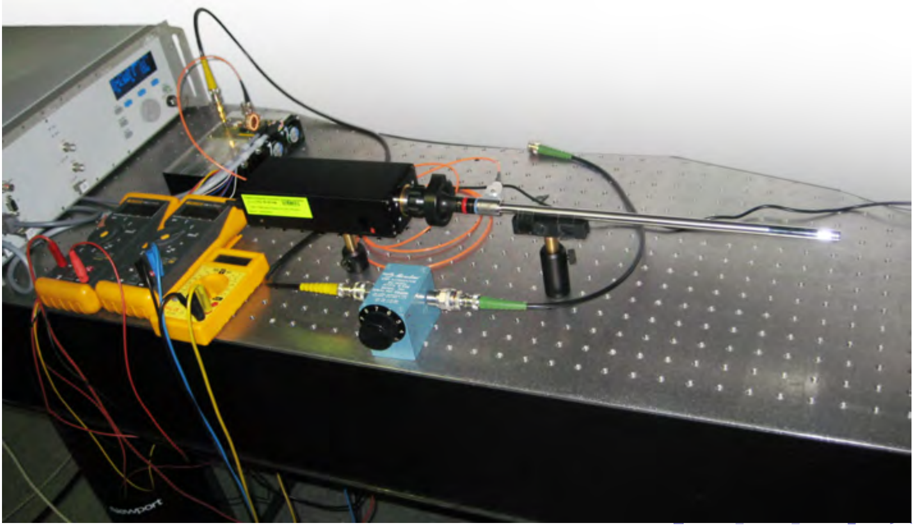
Navigation support - Collision prevention

Finding the entry point to the peritoneal cavity



Preliminary results

Stomach with cubes inside



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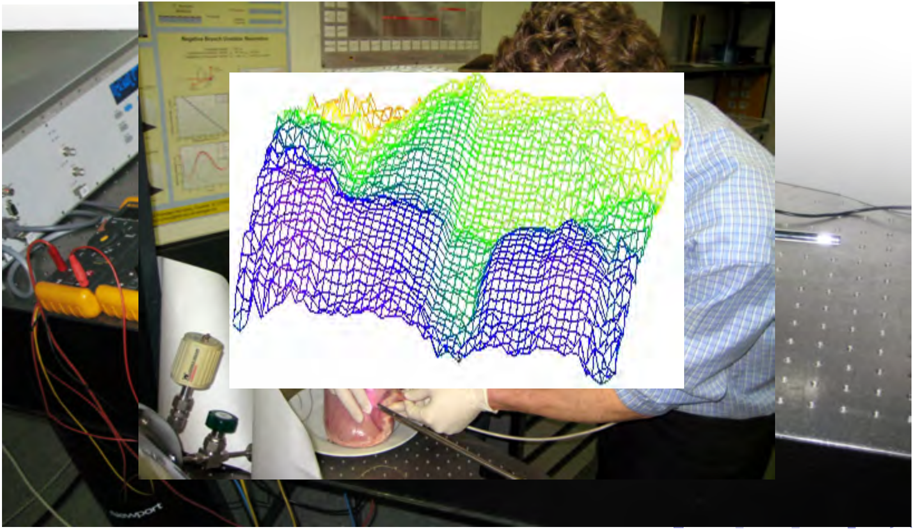

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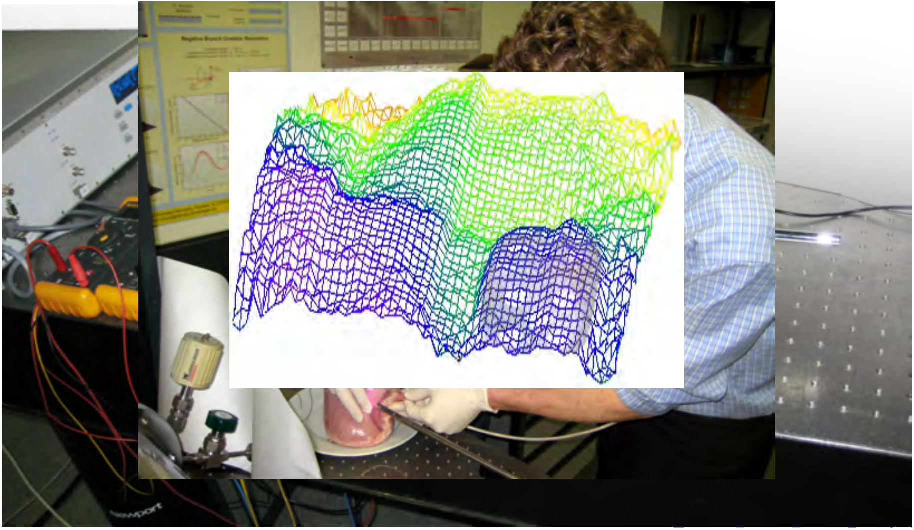

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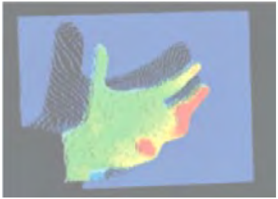


Inertial Measurement Unit

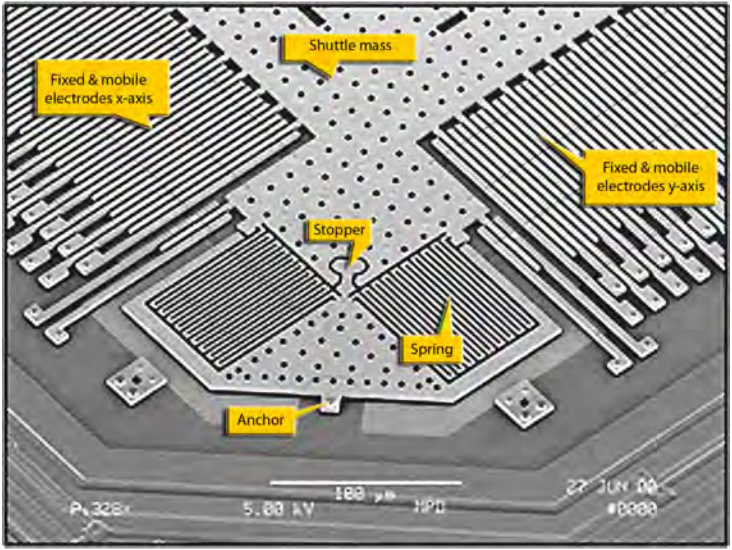
based on a Micro Electro-Mechanical System

Miniaturized silicon structures

- 3-D acceleration measurement without gyroscopes
- Mechanical measurement by proof mass (seismic mass)
- Deflection from neutral position by gravity or acceleration
- Measurement of capacity variation between fixed and mobile electrodes (fingers)
- Very small and thin package
- Detect three axes (triaxial) simultaneously
- Low cost and high volume manufacturing

MEMS

Silicon Mechanical Structure

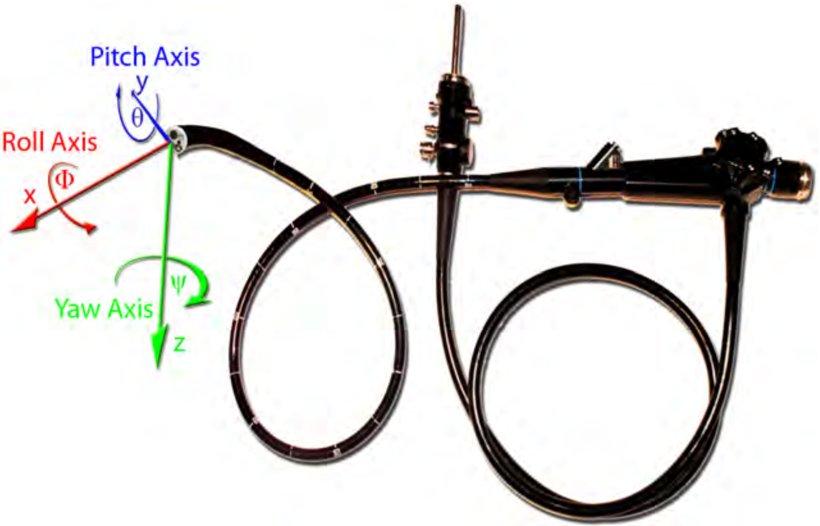


Problem of unknown image orientation

with flexible endoscopy

Roll Pitch Yaw description

for endoscopic orientation

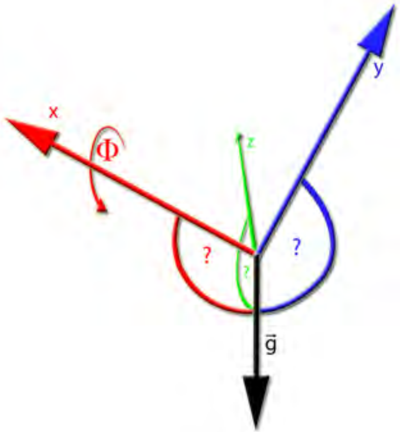


Orientation of endoscope tip

Roll Calculation

How can roll Φ (= orientation of endoscope tip) be calculated out of measured forces on the axes x, y, z and the vector $\vec{g}$ without any further angle information?

$\Rightarrow$ $\vec{x}$, $\vec{y}$ and $\vec{z}$ are orthogonal axes of the Cartesian "board navigation system"



Roll Pitch Yaw (DIN 9300 aeronautical standard)

Measurement of gravity

How have rotation parameters Φ, Θ and Ψ of the IMU (Inertial Measurement Unit) to be chosen to get back to a spatial orientation with $\vec{z} \parallel \vec{g}$?

$$\begin{pmatrix} F_x \\ F_y \\ F_z \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(\Phi) & \sin(\Phi) \\ 0 & -\sin(\Phi) & \cos(\Phi) \end{pmatrix} \cdot \begin{pmatrix} \cos(\Theta) & 0 & -\sin(\Theta) \\ 0 & 1 & 0 \\ \sin(\Theta) & 0 & \cos(\Theta) \end{pmatrix} \cdot \cdot \begin{pmatrix} \cos(\Psi) & \sin(\Psi) & 0 \\ -\sin(\Psi) & \cos(\Psi) & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 0 \\ 0 \\ g \end{pmatrix} = \begin{pmatrix} -\sin(\Theta)g \\ \sin(\Phi)\cos(\Theta)g \\ \cos(\Phi)\cos(\Theta)g \end{pmatrix} \quad (1)$$

with Φ: Roll, Θ: Pitch, Ψ: Yaw
and $F_{x,y,z}$: measured acceleration, g: gravity

Roll computation

Measurement of gravity

Using the two-argument function atan2 to handle the ambiguity one finally can compute **roll** Φ for $F_x \neq \pm g$ and **pitch** Θ for all values:

$$\frac{F_y}{F_z} = \frac{\sin(\Phi)\cos(\Theta)}{\cos(\Phi)\cos(\Theta)} \quad \Rightarrow \quad \Phi = atan2(F_y, F_z) \tag{2}$$

$$F_x = -\sin(\Theta) \cdot g \quad \Rightarrow \quad \Theta = \arcsin\left(\frac{-F_x}{g}\right) \tag{3}$$

As $\vec{g}$ determines just 2 DoF with this approach Yaw Ψ cannot be computed. If $F_x = \pm g$ ($\rightarrow \Theta = \pm\pi \rightarrow F_y = F_z = 0$), roll Φ is not determinable either. To avoid movement influence, correction is only applied if there is no other acceleration or force than gravity g:

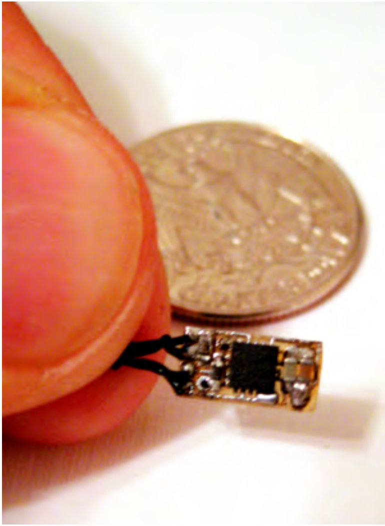
$$F_x^2 + F_y^2 + F_z^2 = g^2 \tag{4}$$

First Prototype

Solution for loss of spatial orientation

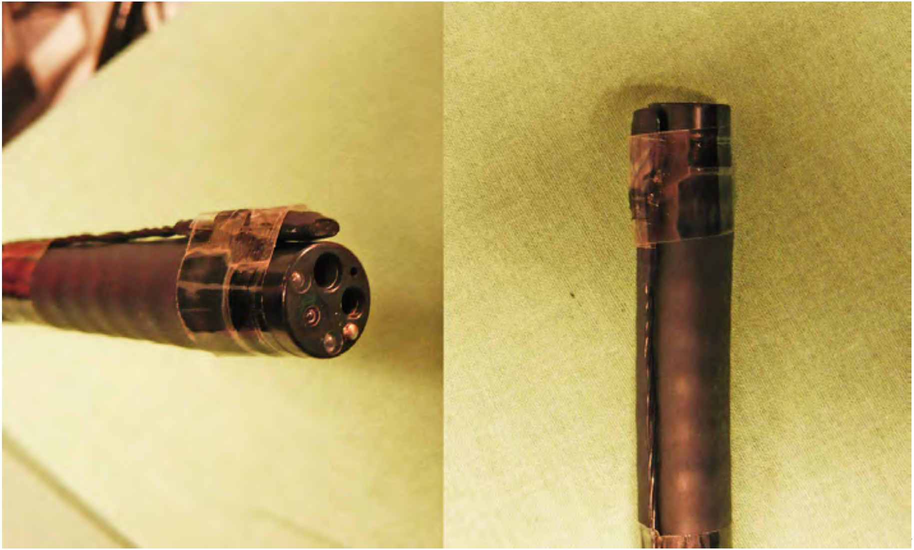
Circuit board with MEMS chip STM LIS331DL for acceleration measurement, 10uF/100nF SMD capacitors for power supply HF denoising and 4k7 SMD resistors for I^2C adaption

- 3-axis MEMS accelerometer
- range $\pm 2g$
- overall size 5x8mm
- communication via two-wire I^2C interface



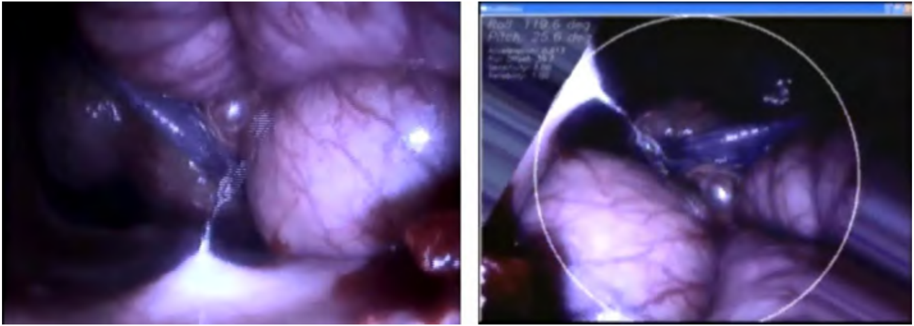
First prototype

external sensor on endoscope's tip



First results

Software solution



Original (l) and rectified (r) image

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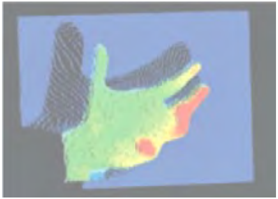

Conclusion

Contributions of an Enhanced Endoscopic Engineering:

- MUSTOF 3-D endoscopy:
  $\Rightarrow$ provides an enhanced off-axis field of view
  $\Rightarrow$ enables collision prevention and motion compensation

- MEMS based inertial measurement:
  $\Rightarrow$ chip is fixed on the endoscope's tip
  $\Rightarrow$ corrects orientation of endoscopic view

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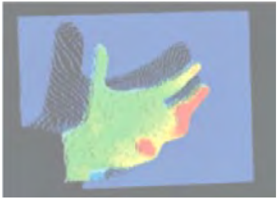

Outlook

Next steps:

- Use new ToF camera with higher resolution (41.000 pixels instead of 3.000 pixels)
- Design rotation correction sensor even smaller (3×6mm)
- Evaluation of accuracy and benefit of both approaches

The End

- Thank you for your attention!
- Any further questions?