Clinical Evaluation of Endorientation

Gravity related rectification for endoscopic images

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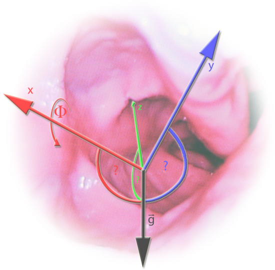
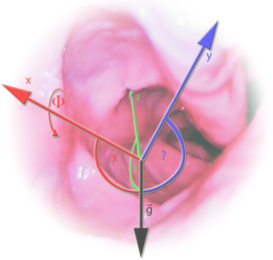
Content



Overview

1 Introduction/Motivation
2 Endorientation approach
- Angle computation
- Down sampling
- Implementation
- Evaluation

3 Summarize
4 Outlook



Time Line

From open surgery to NOTES

Surgery can be done as:

- open surgery
  $\rightarrow$ for hundreds of years
- minimally invasive / laparoscopic surgery
  $\rightarrow$ since the late 80s
- and through natural orifices
  $\rightarrow$ "no longer if but when" (W. O. Richards, D. W. Rattner 2005)

$\Rightarrow$ July 22/23, 2005 white paper and foundation of Consortium for Assessment and Research (NOSCAR) on NOTES: Natural Orifice Translumenal Endoscopic Surgery

Participating groups with NOTES

Great chance for technical innovations

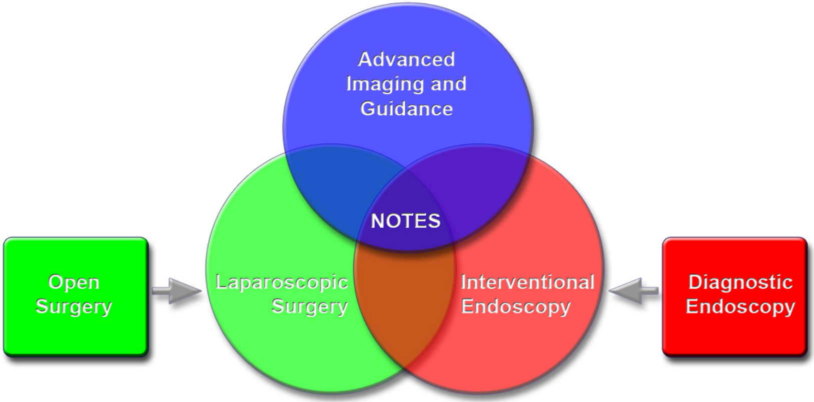


Figure: Interdisciplinarity of Natural Orifice Translumenal Endoscopic Surgery (NOTES)

Improvements

With Natural Orifice Translumenal Endoscopic Surgery (NOTES)

Expected improvements with NOTES:

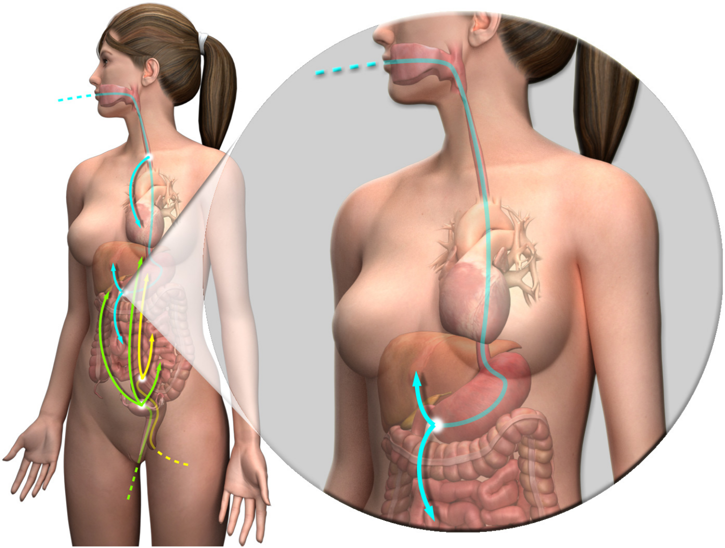
- significantly shortened patients' hospital stays
- no sterile operating room (only instruments)
- new dimension for medical care in developing countries

There will be better help for:

- obese patients
- burn injuries
- children

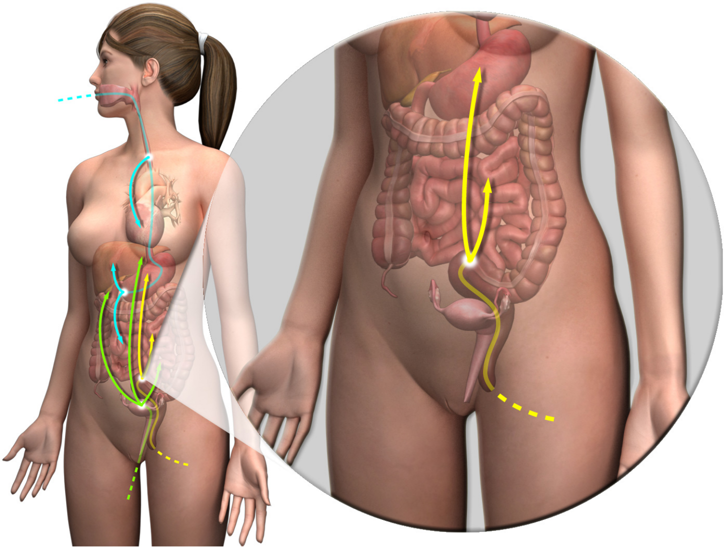
Peroral transgastric route

Natural Orifice Translumenal Endoscopic Surgery



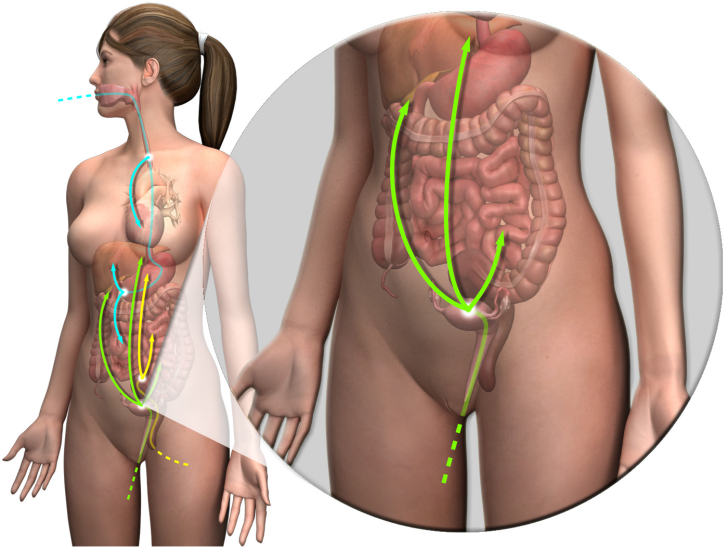
Peranal transcolonic route

Natural Orifice Translumenal Endoscopic Surgery



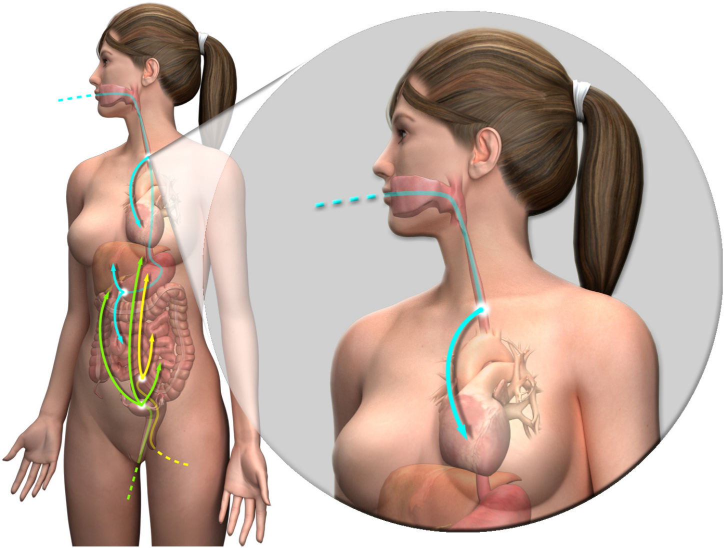
Transvaginal route

Natural Orifice Translumenal Endoscopic Surgery



Peroral transesophageal route

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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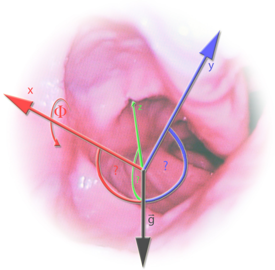

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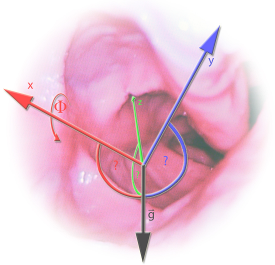

Roll Pitch Yaw description

for endoscopic orientation

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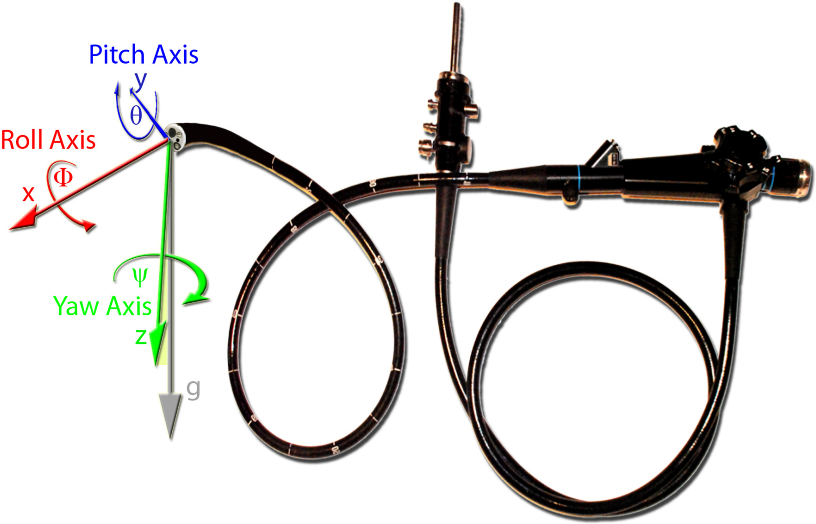
for endoscopic orientation



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 of the arc tangent in a range of $\pm\pi$ one finally can compute **roll** Φ for $F_x \neq \pm g$ and **pitch** Θ for all values:

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

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

Limitations

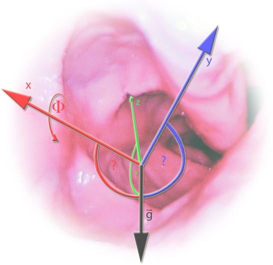
Measurement of gravity

Orientation computation is limited:

- $\vec{g}$ determines just two degrees of freedom
  $\Rightarrow$ **yaw Ψ cannot be computed** at any time
- singularity occurs at $F_x = \pm g$ ($\Theta = \pm\pi \rightarrow F_y = F_z = 0$)
  $\Rightarrow$ roll Φ can not be computed when the endoscope **points downward**
- no calculation during **high superposed acceleration** ΔF_{absmax}
  $\Rightarrow$ angle is freezed untill $\Delta F < \Delta F_{absmax}$ is reached again

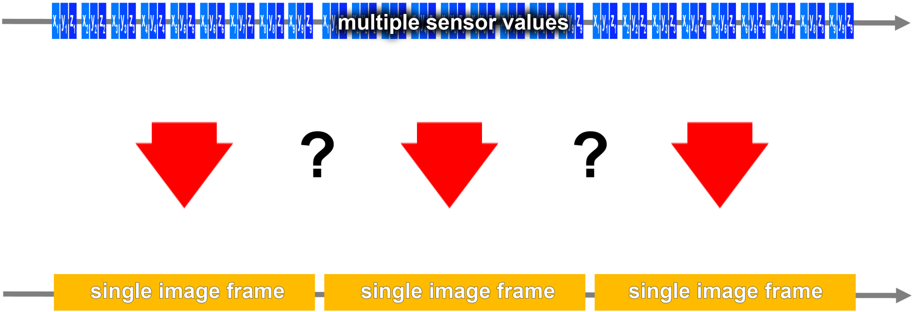
$$|\sqrt{F_x^2 + F_y^2 + F_z^2} - g| < \Delta F_{absmax} \tag{4}$$

Overview



Down sampling and peak filtering algorithm

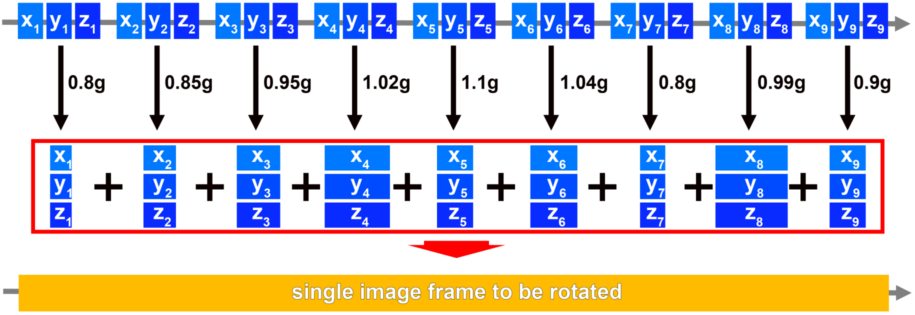
Multiple sensor values during a single image frame



Down sampling from 400Hz sensor data to 30Hz video frame rate:
Downsampling process usable for filtering?

Down sampling and peak filtering algorithm

Add weighted values to rotate new image frame



Weighted Sum:
- + less movement influence (weighting)
- + noise reduction (more values)

Down sampling

by summing up weighted samples

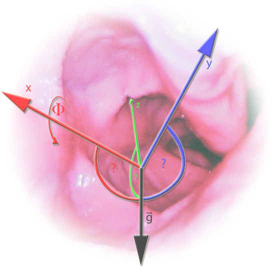
All n sensor values F_{x_i}, F_{y_i} and F_{z_i} within an image frame with $i = 1, ..., n$ are summed up and weighted with a factor w_i with maximal weight $\frac{1}{w_0}$:

$$w_i = \frac{1}{w_0 + |g - \sqrt{F_{x_i}^2 + F_{y_i}^2 + F_{z_i}^2}|} \tag{5}$$

Afterwards the sum has to be normalized by the sum of all weighting factors w_i:

$$\begin{pmatrix} F_x \\ F_y \\ F_z \end{pmatrix} = \sum_{i=1}^{n} (\begin{pmatrix} F_{x_i} \\ F_{y_i} \\ F_{z_i} \end{pmatrix} \cdot w_i) \cdot (\sum_{i=j}^{n} (w_j))^{-1} \tag{6}$$

Overview



Endorientation algorithm

Block diagram with external microcontroller

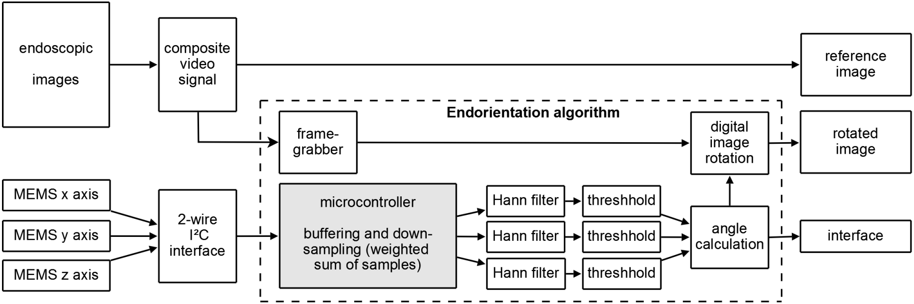


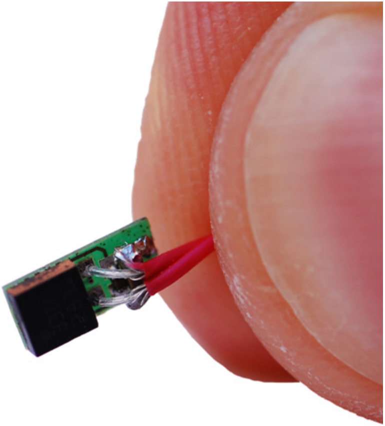
Figure: Principle of Endorientation algorithm II

Tiny Prototype

Solution for loss of spatial orientation

Circuit board with MEMS chip STM LIS331DL for acceleration measurement and SMD capacitors for power supply HF denoising

- 3-axis MEMS accelerometer
- 0402 10uF/100nF capacitors
- range ± 2.3g
- overall size 3x7mm
- communication via two-wire I^2C interface



Endorientation Hardware: EndoSens

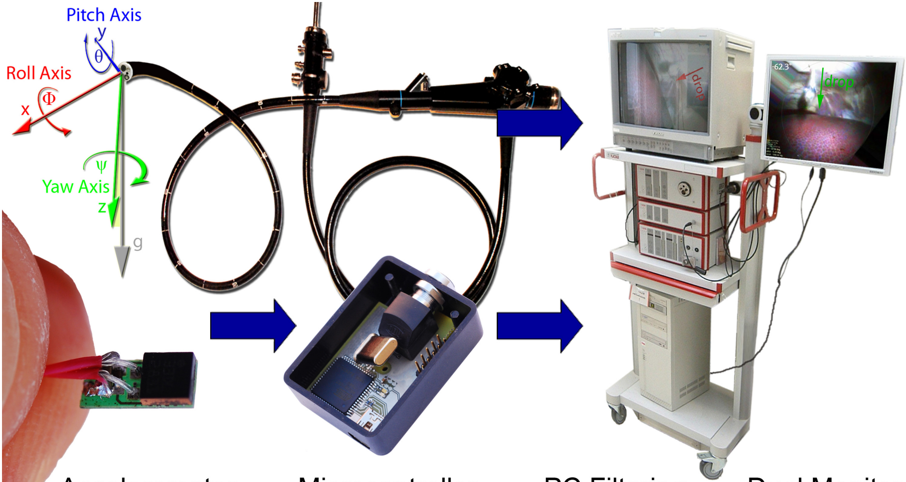
External Microcontroller for down sampling and filtering

EndoSens microcontroller implementation of the Endorientation algorithm:

- 8-bit Atmel AVR200 microcontroller
- overall size 35x50mm
- I^2C input with 400 samples/s
- internal down sampling and filtering
- USB output with 30 values/s
- powered by USB

Endorientation Hardware

Accelerometer - microcontroller - computer - monitor



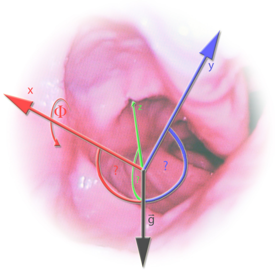
Accelerometer Measurements

Microcontroller Downsampling

PC Filtering GPU Rotation

Dual Monitor Visualization

Overview



Evaluation prototype

external sensor on endoscope's tip

Clinical Evaluation

with an animal study

- Settings:
  - rectal introduced flexible endoscope
  - Grasp four different markers in the phantom (right upper, left lower, right lower and left upper quadrant) with trans-abdominal introduced instruments
  - Only the original endoscopic view and additionally a rectified horizon were shown alternately
  - Surgeon’s hand movements were tracked and time was recorded

- Results:
  - markers were reached in **signifcantly less time** (by factor 2)
  - path lengths were **signifcantly shorter** (by factor 2)
  - Especially navigation in the lower abdomen is **extremely difficult** without image rotation (retroflexed position)

Clinical Evaluation

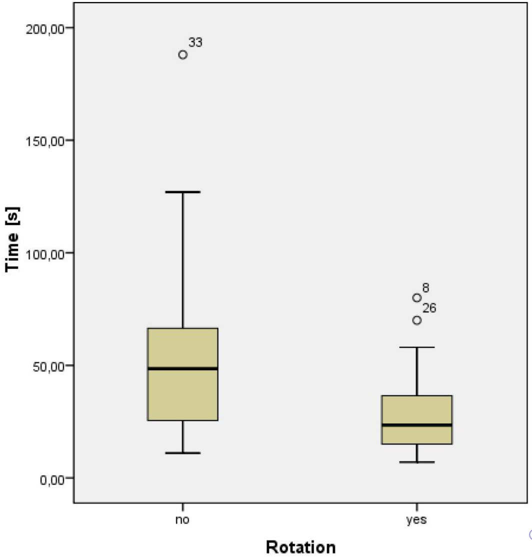
Average time comparison without and with image rectification

- Unsupported task:

  $n = 20$ times
  mean $\mu_{\text{orig}} = 53.95s$
  stdd $\sigma_{\text{orig}} = 41.55s$

- Supported task:

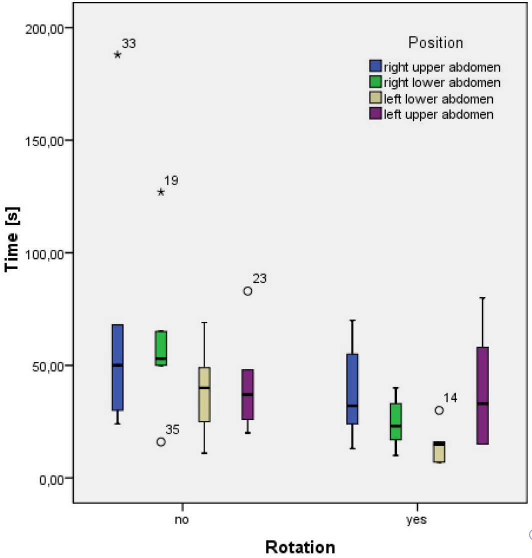
  $n = 20$ times
  mean $\mu_{\text{rect}} = 29.65$
  stdd $\sigma_{\text{rect}} = 21.15$



Clinical Evaluation

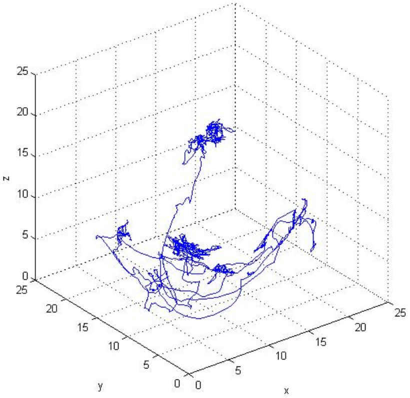
Quadrant time comparison without and with image rectification

- μ upper right abdomen 72.00s ($\pm$67.13s) vs. 38.8s ($\pm$23.27s)
- μ lower right abdomen 62.2s ($\pm$40.54s) vs. 24.6s ($\pm$12.05s).
- μ lower left abdomen 38.8s ($\pm$22.25s) vs. 15s ($\pm$9.41s)
- μ upper left abdomen 42.8s($\pm$24.89s) vs. 40.2s ($\pm$28.38s)



Clinical Evaluation

Original vs. rectified images: total path length of 650 vs. 317 inches



Surgeon's hands' movements without (left) and with (right) rectification.

Clinical Endosens prototype evaluation

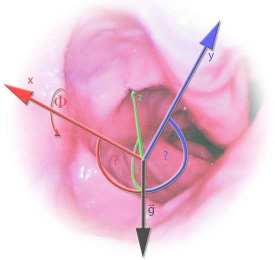
Drop test with animal study

Clinical Endosens prototype evaluation

Drop test with animal study

Figure: Drop Test original (l) vs. rectified (r)

Overview



Conclusion

- Challenge:
  ⇒ use of flexible endoscopes with NOTES interventions
  ⇒ loss of spatial orientation esp. for surgeons
- Idea:
  ⇒ fix a tiny inertial sensor on a flexible endoscope's tip
  ⇒ rectify orientation of endoscopic view, provide a stable horizon
- Solution:
  ⇒ sensor board with MEMS accelerometer and I2C communication
  ⇒ EndoSens micro controller board with down sampling, filtering, threshholding and USB communication
- Evaluation:
  ⇒ less time, shorter paths, easier handling
  ⇒ interventions with flexible endoscopes easier esp. for surgeons

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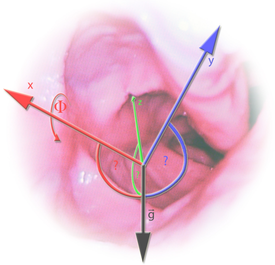
3. Summarize
4. **Outlook**



Outlook

Better technical evaluation of down sampling and filtering

- testing algorithms with synthetic data (collision / continuous tremor)
- testing in a surgery simulation area (rotary table)
- mosaiking/stitching based on rectified images
- finding an industrial partner!!!

The End

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