Endoscopic Orientation Correction

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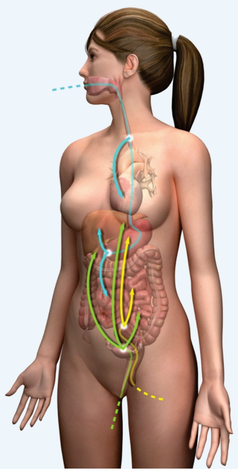
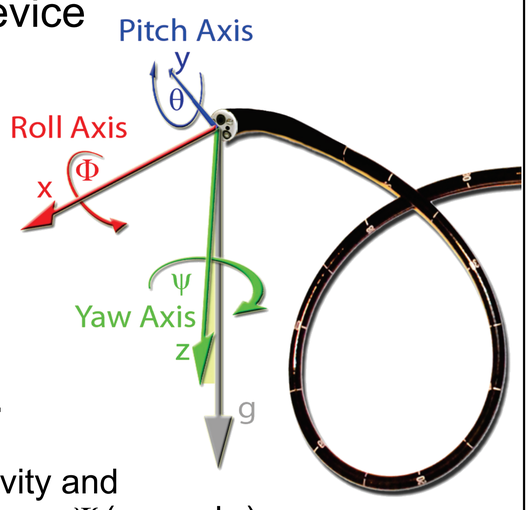
Introduction



- Natural Orifice Translumenal Endoscopic Surgery (NOTES) is a new promising field.
- A still unsolved problem with flexible endoscopy is the missing information about the image orientation [1].
- Tip retro-flexion of a non-rigid endoscope causes image rotation angles up to ± 180 *degrees* [2].

Idea

- Simple idea: Integrate a Micro Electro-Mechanical System (MEMS) based inertial sensor device in the endoscope's tip.
- Measures influencing forces in three orthogonal directions.
- If not moving, only acceleration of gravity has an effect on the three axes [3].
- Correlation of forces and angles.



With $F_{x,y,z}$: measured acceleration, g: gravity and roll Φ (around x), pitch Θ (around y) and yaw Ψ (around z)

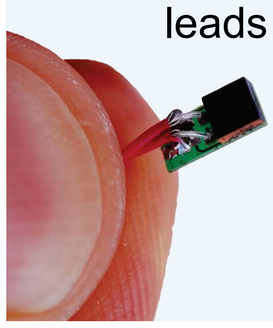
Method

- How to chose IMU (Inertial Measurement Unit) rotation parameters to get back to a spatial orientation with $z \parallel g$?

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

With $\mathbf{R}_\Phi$, $\mathbf{R}_\Theta$ and $\mathbf{R}_\Psi$: Roll Pitch Yaw rotation matrices around x, y and z

- To handle ambiguity for $\pm\pi$ the two-argument function atan2 leads to roll Φ for $F_x \neq \pm g$ and pitch Θ for all values:



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

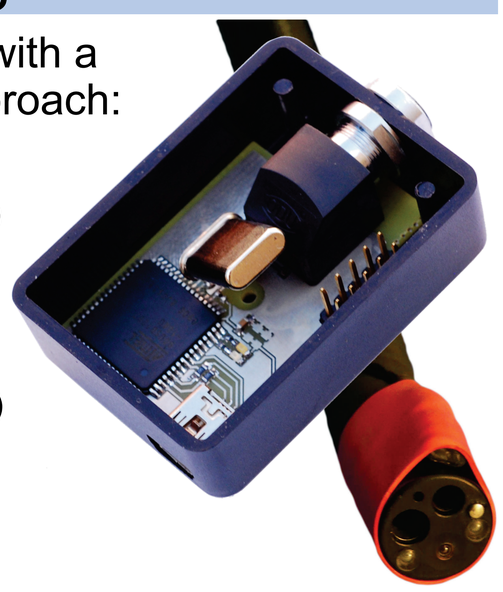
$$F_x = -\sin(\Theta)\cdot g \Rightarrow \Theta = \arcsin\left(\frac{-F_x}{g}\right) \quad (3)$$

Filtering

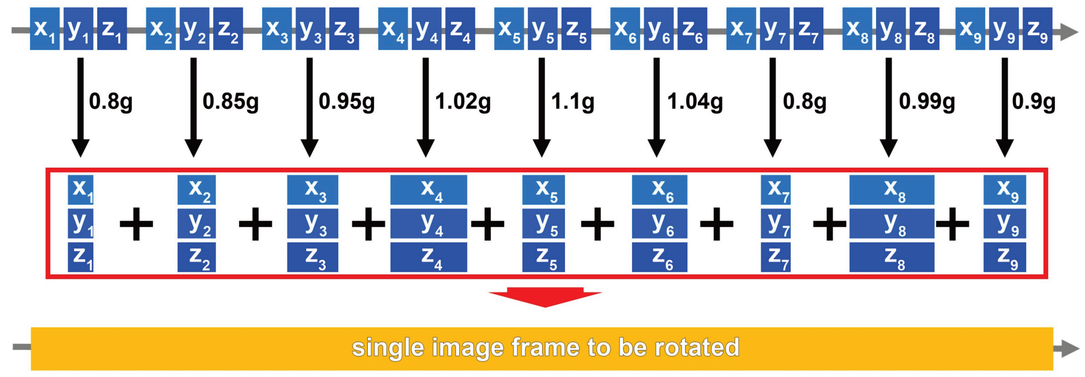
- Filtering over n samples is done with a new intelligent weighted sum approach:

$$\begin{pmatrix} F_x \\ F_y \\ F_z \end{pmatrix} = \sum_{i=1}^{n} \left(\begin{pmatrix} F_{x_i} \\ F_{y_i} \\ F_{z_i} \end{pmatrix} \cdot w_i \right) \cdot \left(\sum_{j=1}^{n} (w_j) \right)^{-1} \quad (3)$$

$$w_i = \frac{1}{\frac{1}{w_0} + \left| g - \sqrt{F_{x_i}^{\,2} + F_{y_i}^{\,2} + F_{z_i}^{\,2}} \right|} \quad (4)$$



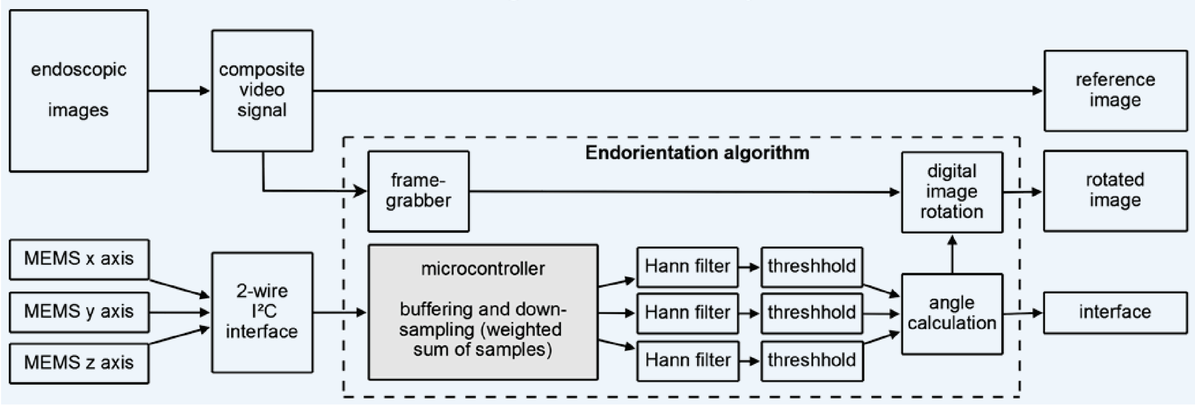
- Triples far away from gravity g have less impact:



Implementation

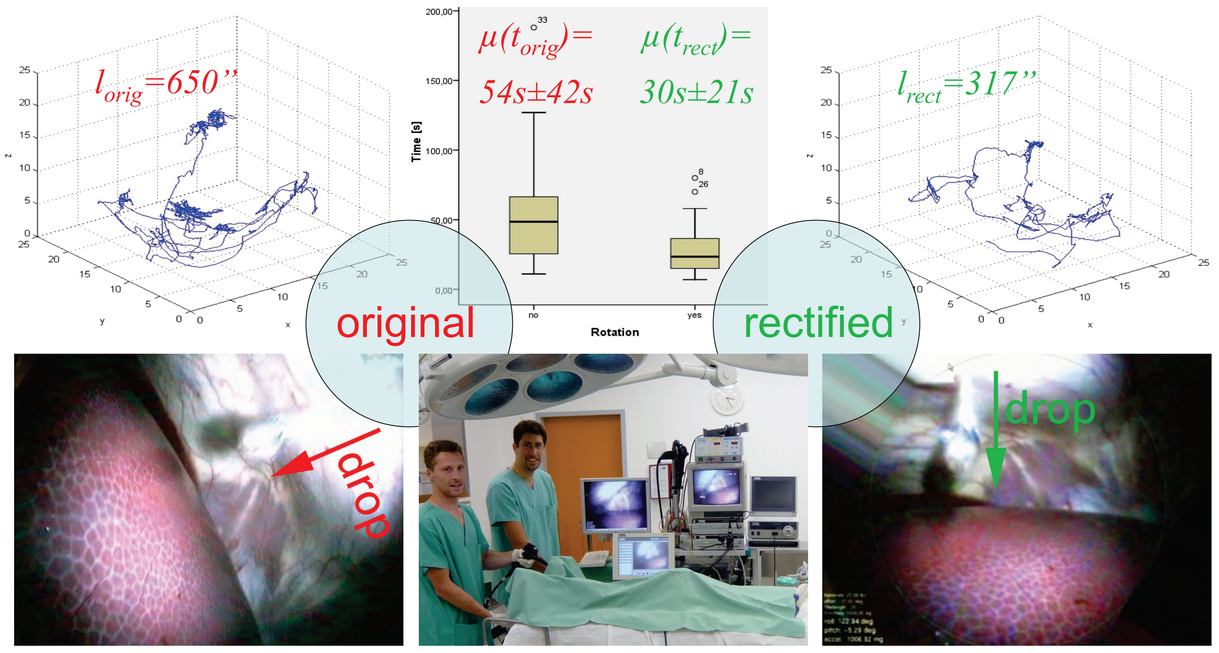
Two-step "Endorientation" algorithm for use of sensor data:

1. Fast down sampling and weighted sum filtering on "EndoSens" micro controller hardware.
2. Parameter controlled Hanning and threshold filtering and GPU-based image rotation by PC software:



Clinical Evaluation

- Path length l, duration t, drop test: Original vs. rectified:



Conclusion

- Achievable repetition rate is above the common endoscopic video frame rate of $30Hz$ even after filtering.
- Shock-resistant accuracy is about one degree.
- Image rotation is performed digitally in real-time.
- Clinical Evaluation: Significantly improved accuracy with by factor 2 shorter paths and nearly half the duration.
- Movement and Coordination of different instruments were rated to be much more intuitive with a stable horizon.

[1] Rattner, D., Kalloo, A.: ASGE/SAGES working group on NOTES: White Paper October 2005. Surg. Endosc. 20 (2006) 329-333
[2] Höller, K. et al.: Clinical evaluation of Endorientation: Gravity related rectification for endoscopic images. In: Proc. 6th IS ISPA, Salzburg. (2009) 713-717
[3] Höller, K. et al.: Suppression of shock based errors with gravity related endoscopic image rectification", In Proc. 5th Russian-Bavarian Conference on Bio-Medical Engineering, Munich. (2009) 43-45

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