Wireless Capsule Endoscope

Motion Estimation based on Multiscale Elatisc Registration

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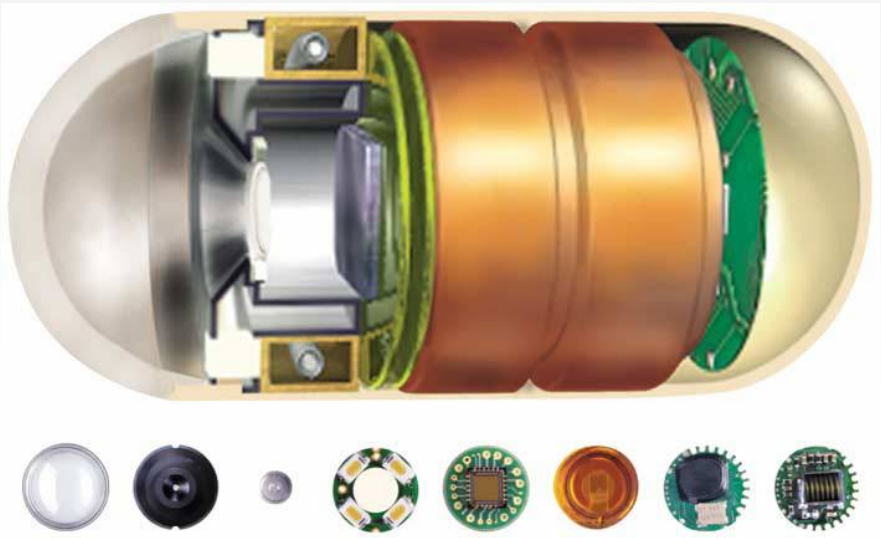
What is Wireless Capsule Endoscope?

- New technology for gastrointestinal tract examination

Wireless Capsule Endoscope (WCE) [1]

Capsule Components



- Lens
- Light source
- Camera chip
- Battery
- Transmitter
- Antenna

Capsule Endoscopy Procedure

Capsule Endoscopy Procedure

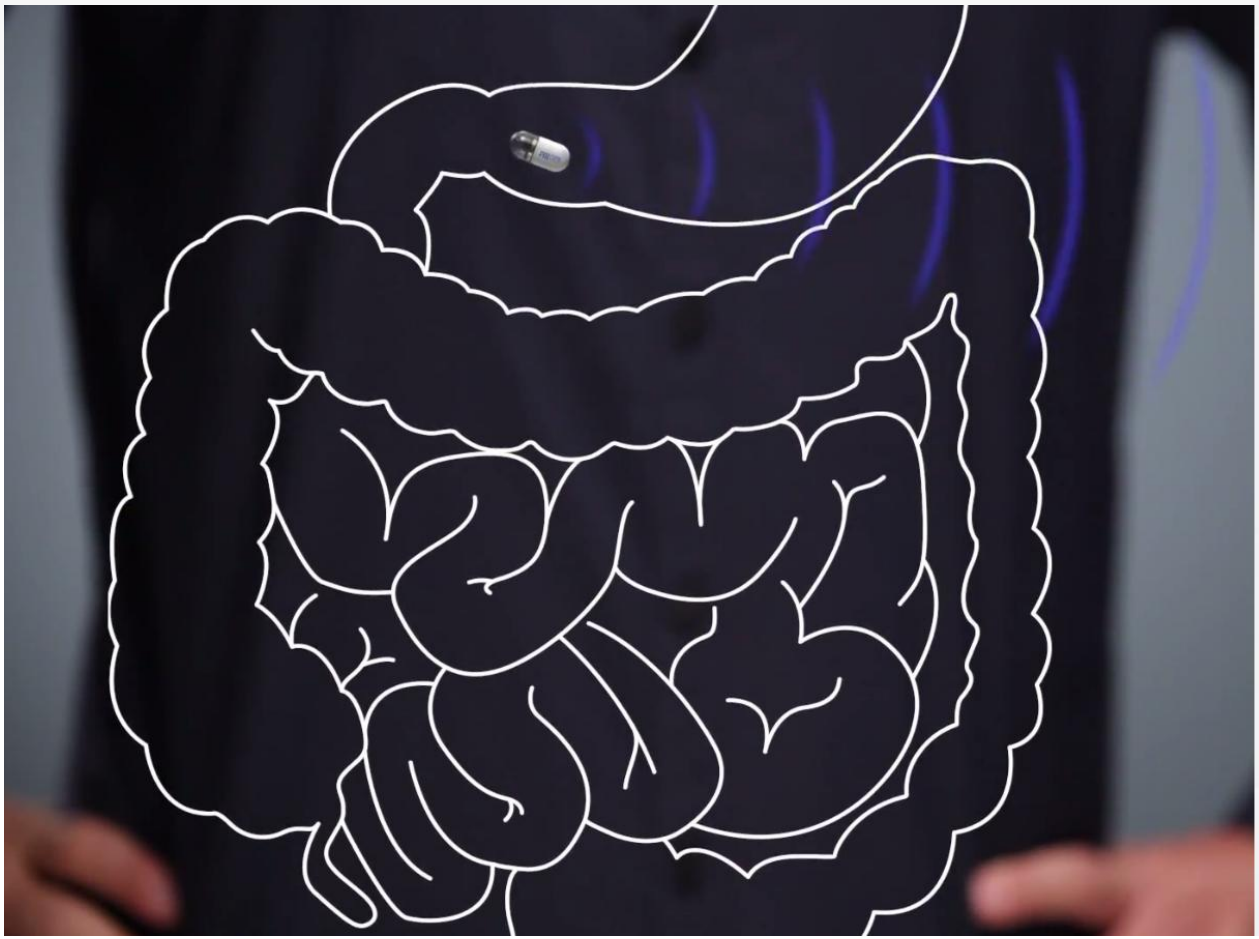
(video.avi)

Capsule Endoscopy Procedure

(video.avi)

Capsule Endoscopy Procedure

- All the images (+ 50.000) are saved for later analysis



Capsule Endoscopy Video

Capsule Endoscopy Video

(video.avi)

Capsule Endoscopy Video

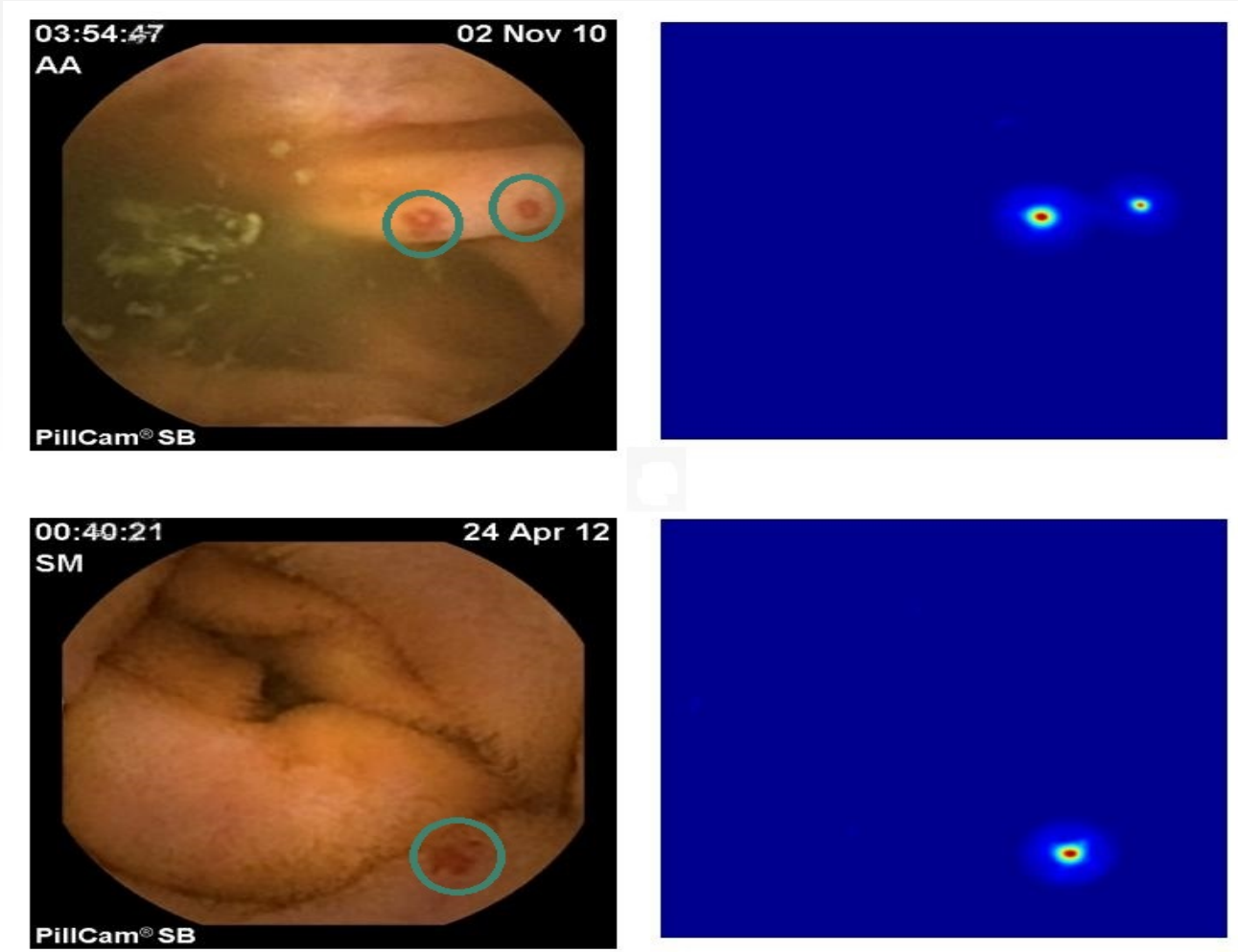
(video.avi)

Why is Capsule Endoscopy done?

Detection of diseases and disorders of the small intestine

- Bleeding
- Polyps
- Parasite
- Inflammatory Disease
- Crohn's Disease
- Celiac Disease

Bleeding Detection



Computer-assisted bleeding detection [2]

Parasite Detection

Parasite Detection

(video.avi)

Parasite Detection

(video.avi)

Capsule Endoscopy Advantages

- Painless and Comfortable (patients can follow their normal routine)
- Non-invasive (no side effects or complications)
- Accurate and effective diagnostic tool (high quality images)

Capsule Endoscopy Limitations

- Inability to perform a biopsy or treat any pathology seen

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(video.avi)

Capsule Endoscopy Limitations

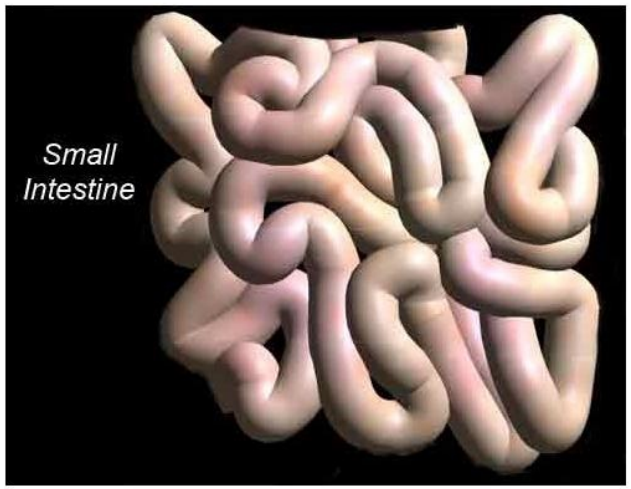
- Inability to perform a biopsy or treat any pathology seen

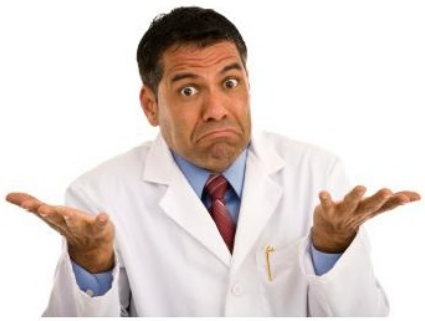
(video.avi)

Capsule Endoscopy Limitations

Impossible to control and localize the capsule endoscope

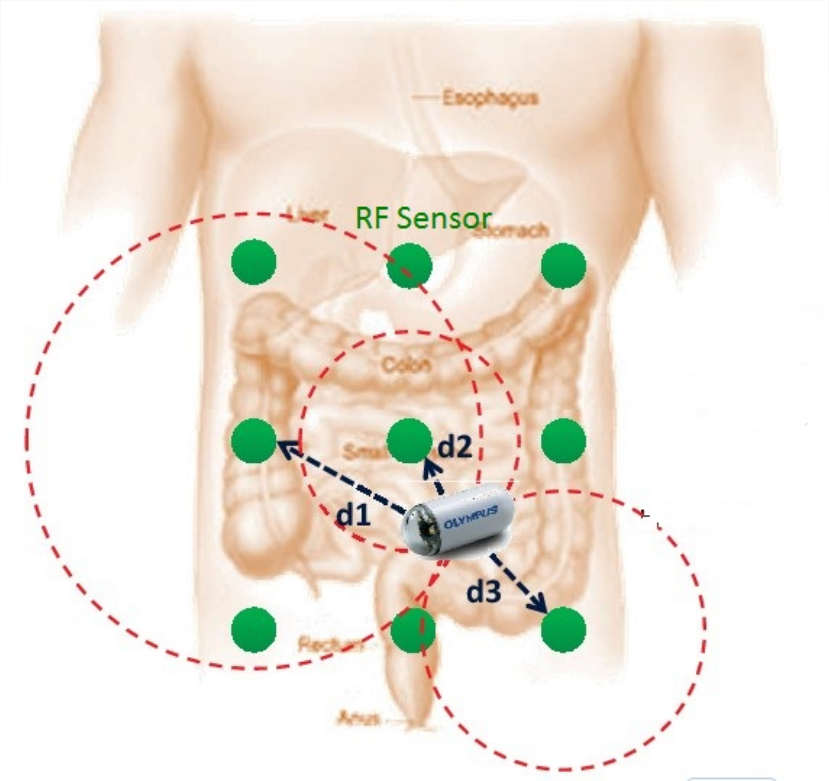
When an abnormality is detected it is very difficult to know where it is located





Capsule Endoscope Localization

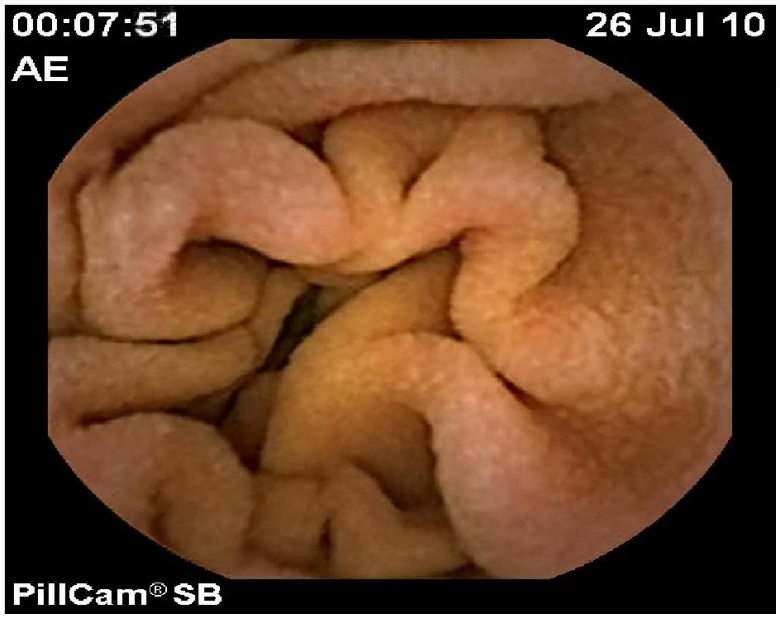
- Network of sensors attached to the body



A typical sensor-based localization system [3]

Capsule Endoscope Localization

Video-based methods using image registration techniques



- How to estimate motion from consecutive frames?

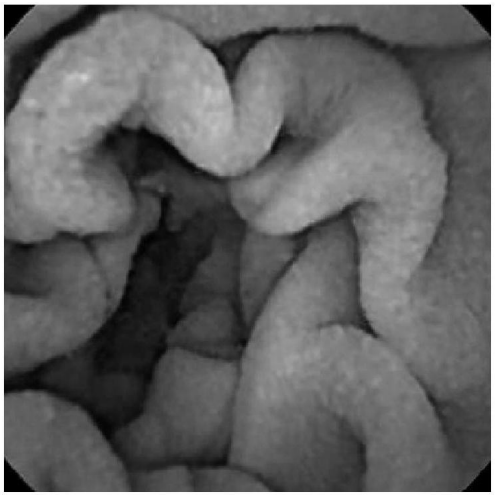
Image Registration

The Problem

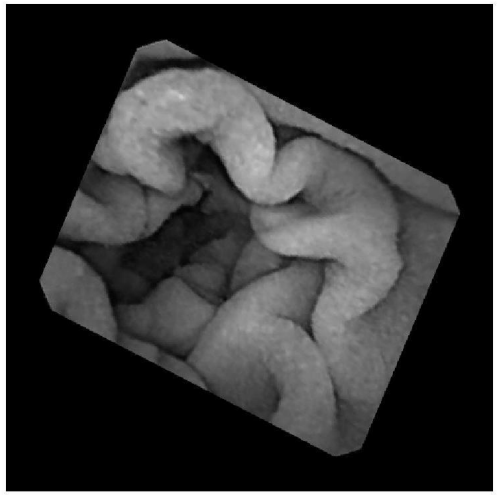
Given a template image T and a reference image R

$$R, T : \Omega \longrightarrow \mathbb{R}, \quad \Omega \subset \mathbb{R}^2$$

find a transformation $u : \Omega \longrightarrow \mathbb{R}^2$ such that $T(u) \approx R$



Reference R



Template T

Image Registration

- How to measure similarity $T(u) \approx R$? $\rightsquigarrow D$
- What kind of transformation u?
- u is a reasonable transformation? $\rightsquigarrow S$

Variational Formulation

Given T and R find u such that

$$\min_u \; D(T(u), R) + \alpha S(u)$$

D - distance measure

S - regularization term

Image Registration

- Affine transformation

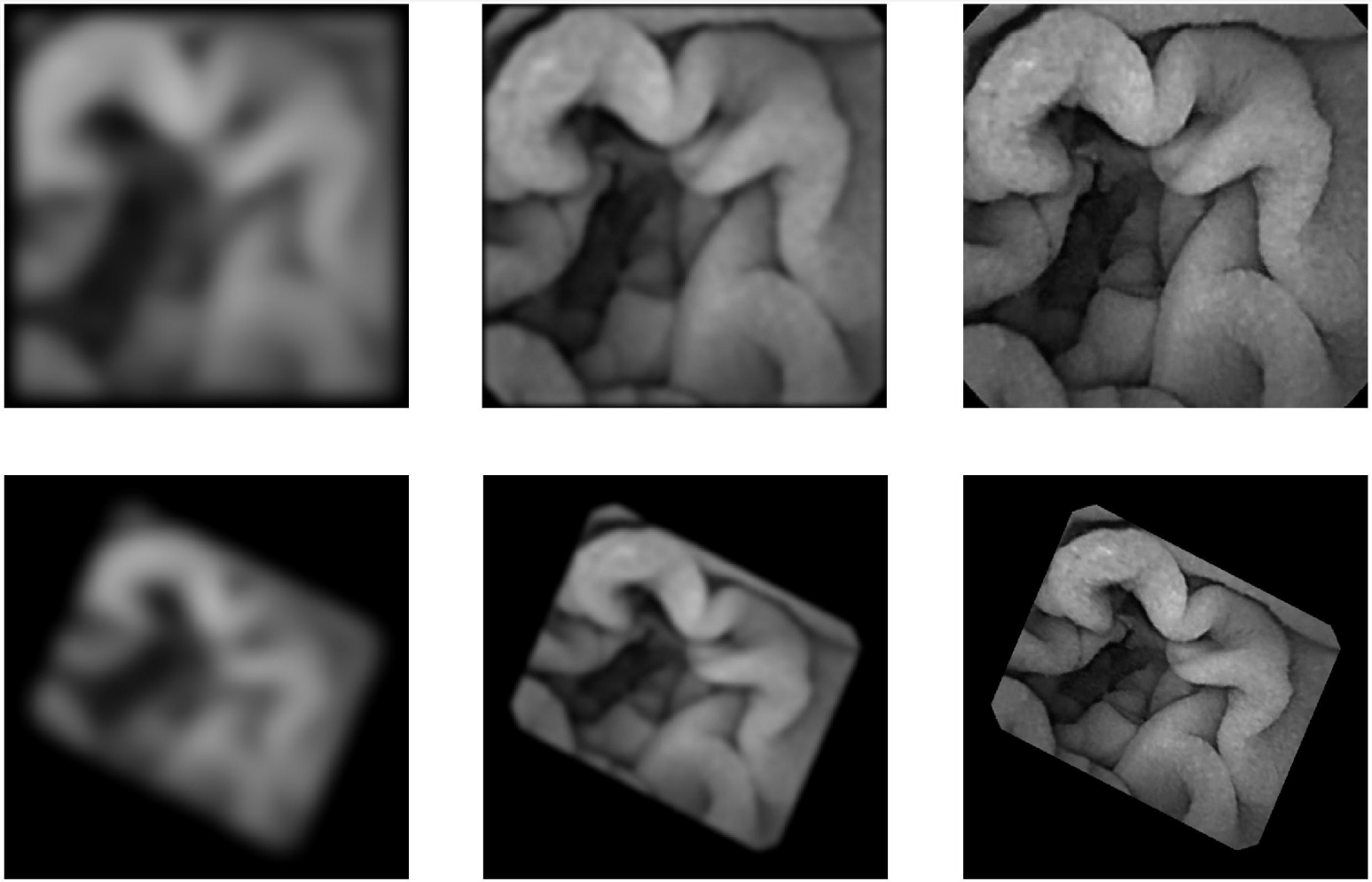
$$u = \begin{bmatrix} s & 0 & 0 \\ 0 & s & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} cos(\theta) & sin(\theta) & 0 \\ -sin(\theta) & cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & t_x \\ 0 & 1 & t_y \\ 0 & 0 & 1 \end{bmatrix}$$

- $D(T(u), R)) = \frac{1}{2}\|T(u) - R\|^2_{L^2}$ (SSD)

- S(u) = 0

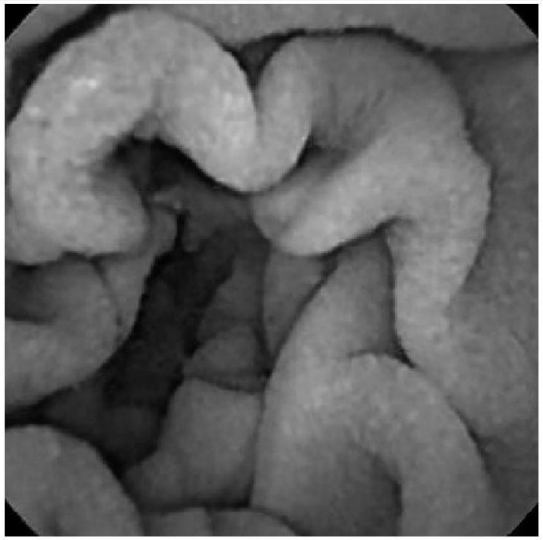
- Minimization technique: Gauss-Newton (+ Multiscale) [4]

Image Registration

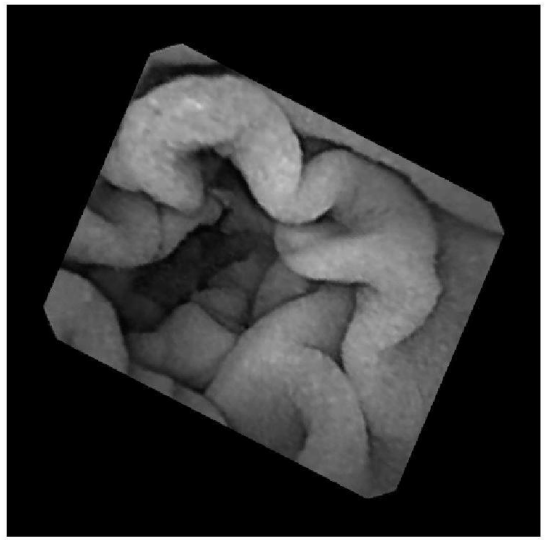


Multiscale image registration

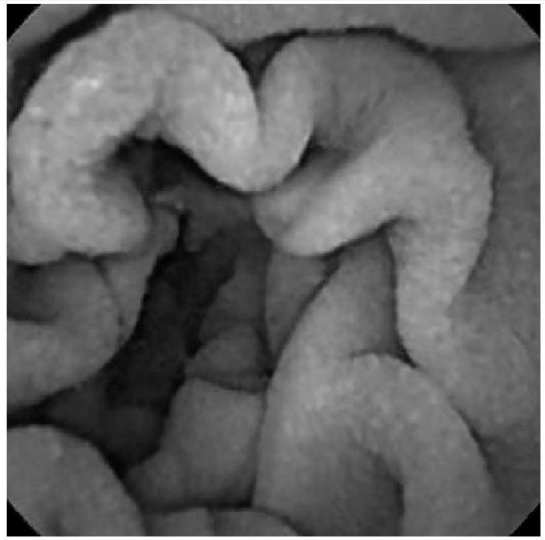
Image Registration



Reference R



Template T

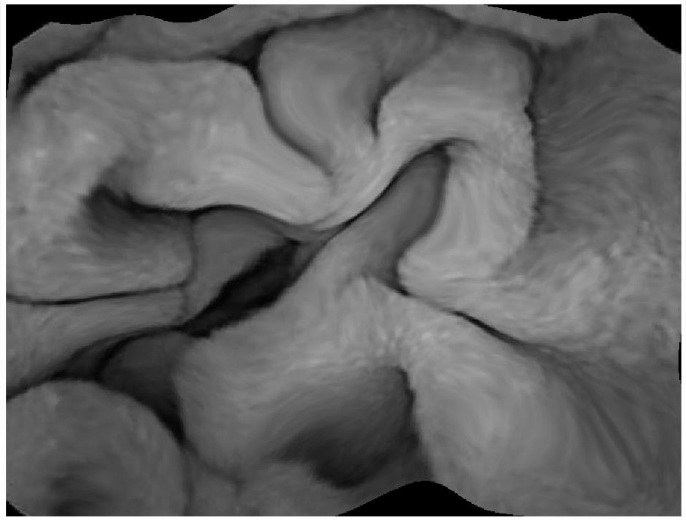


Transformed $T(u)$

- Solution: $s = 1.1, \quad \theta = 25$
- Numerical: $s = 1.1119, \quad \theta = 25.003$

Image Registration

Reference R



Template T

- What transformation u?
- More Flexibility $\rightsquigarrow$ Non-parametric transformation u
- Regularizer $S(u)$?

Image Registration

Elastic Regularizer

$$S(u) = \int_\Omega \frac{\lambda + \mu}{2} \|\nabla \cdot u\|^2 + \frac{\mu}{2} \sum_{i=1}^{2} \|\nabla u_i\|^2 \, dx$$

- Linear elasticity model (Hooke's law)
- The image is modeled as an elastic body

Image Registration

- Variational Formulation

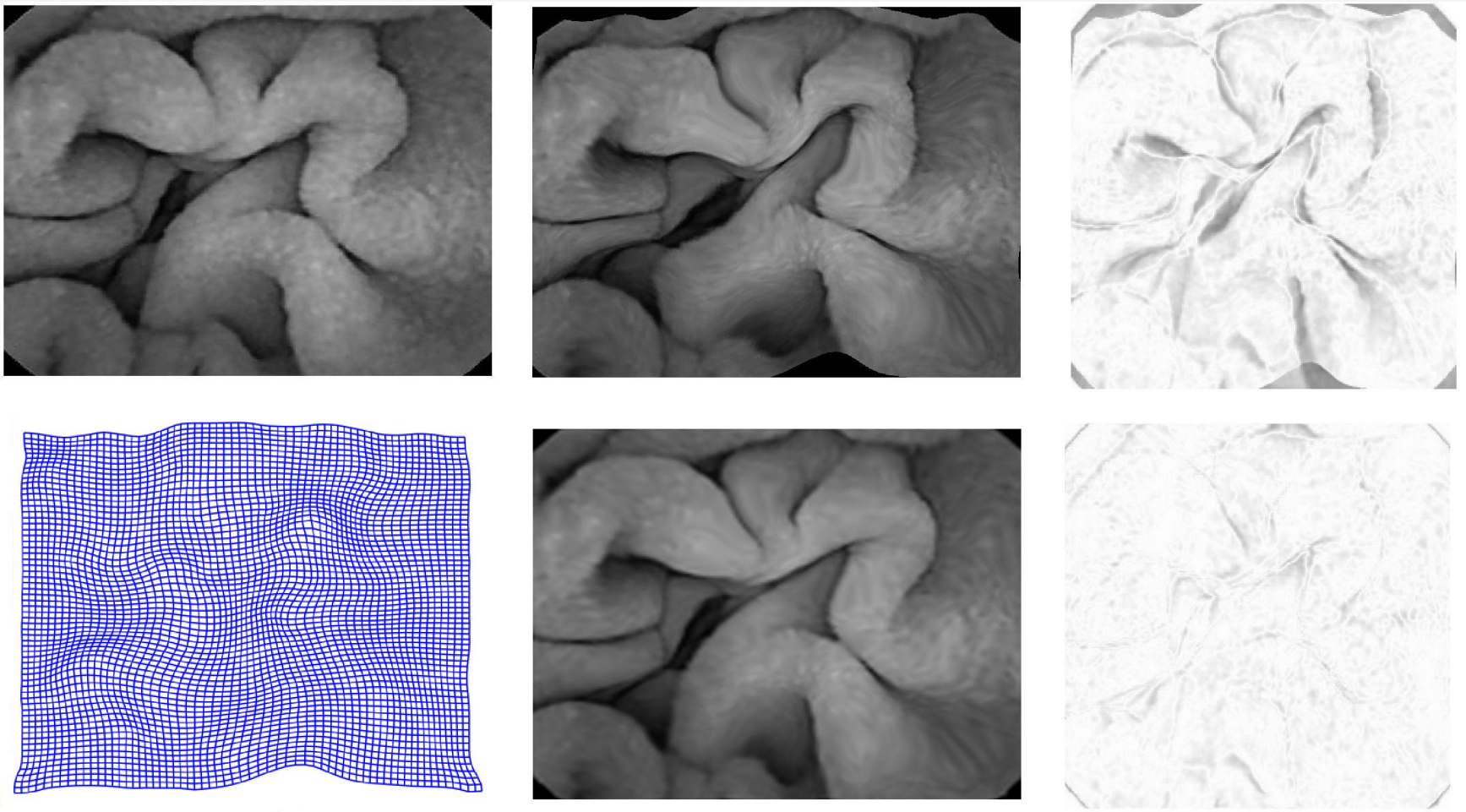
$$\min_{u} \; D(T(u), R) + \alpha S(u)$$

Euler-Lagrange Equations

$$\alpha A(u) - f(u) = 0$$

- Elastic Regularizer: $A(u) = \mu \triangle u + (\lambda + \mu) \nabla (\nabla \cdot u)$
- SSD: $f(u) = -(R - T(u)) \nabla T(u)$

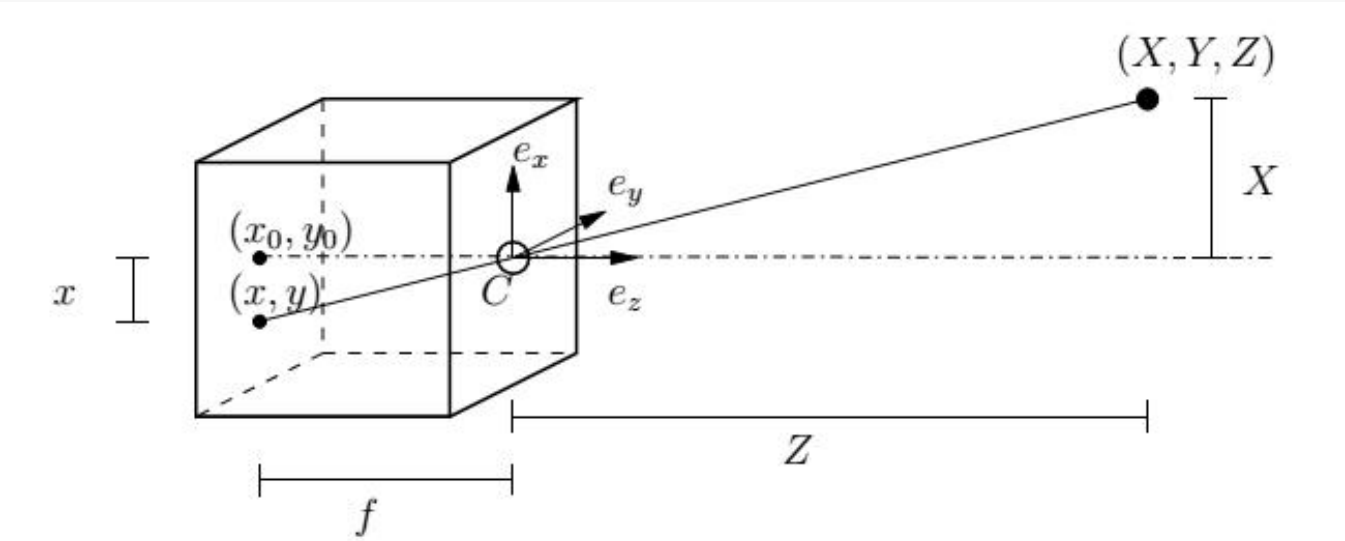
Image Registration



Top, left to right: R, T, and |R-T|. Bottom, left to right: u, T(u), and |R-T(u)|

Modeling Cameras

- WCE camera approximates the pinhole model [5]



- Projective geometry

$$x = f\frac{X}{Z} \qquad \text{and} \qquad y = f\frac{Y}{Z} \tag{1}$$

Modeling Cameras

- WCE movement is modeled by an affine transformation (scaling, rotation, and translation)
- In consecutive frames, after Affine registration, we have

$$X_2 = sX_1 \tag{2}$$

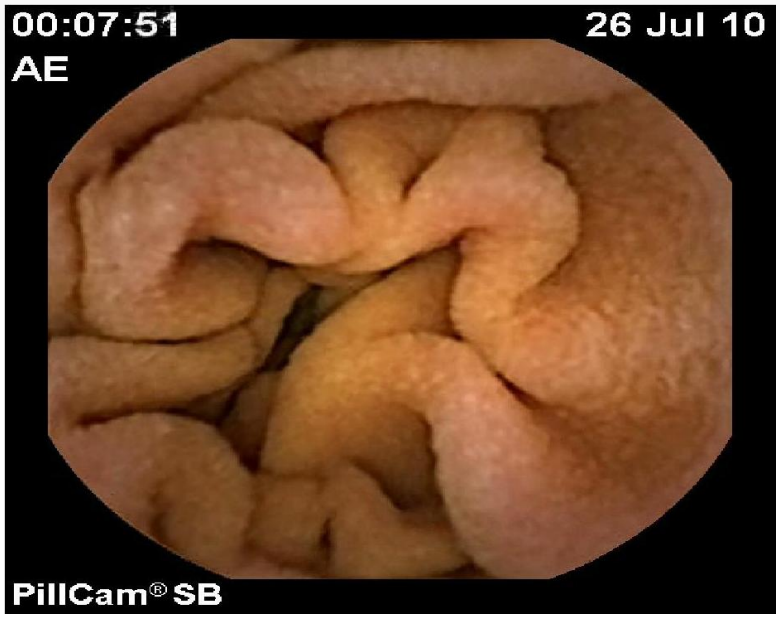
- From (1) and (2)

$$\frac{Z_2}{Z_1} = s\frac{x_1}{x_2}$$

To estimate the relative displacement of WCE we only need to estimate s

Intestine wall deformation

- Nonrigid deformation of the intestine wall?



- The intestine wall is modeled as an elastic body

Methodology

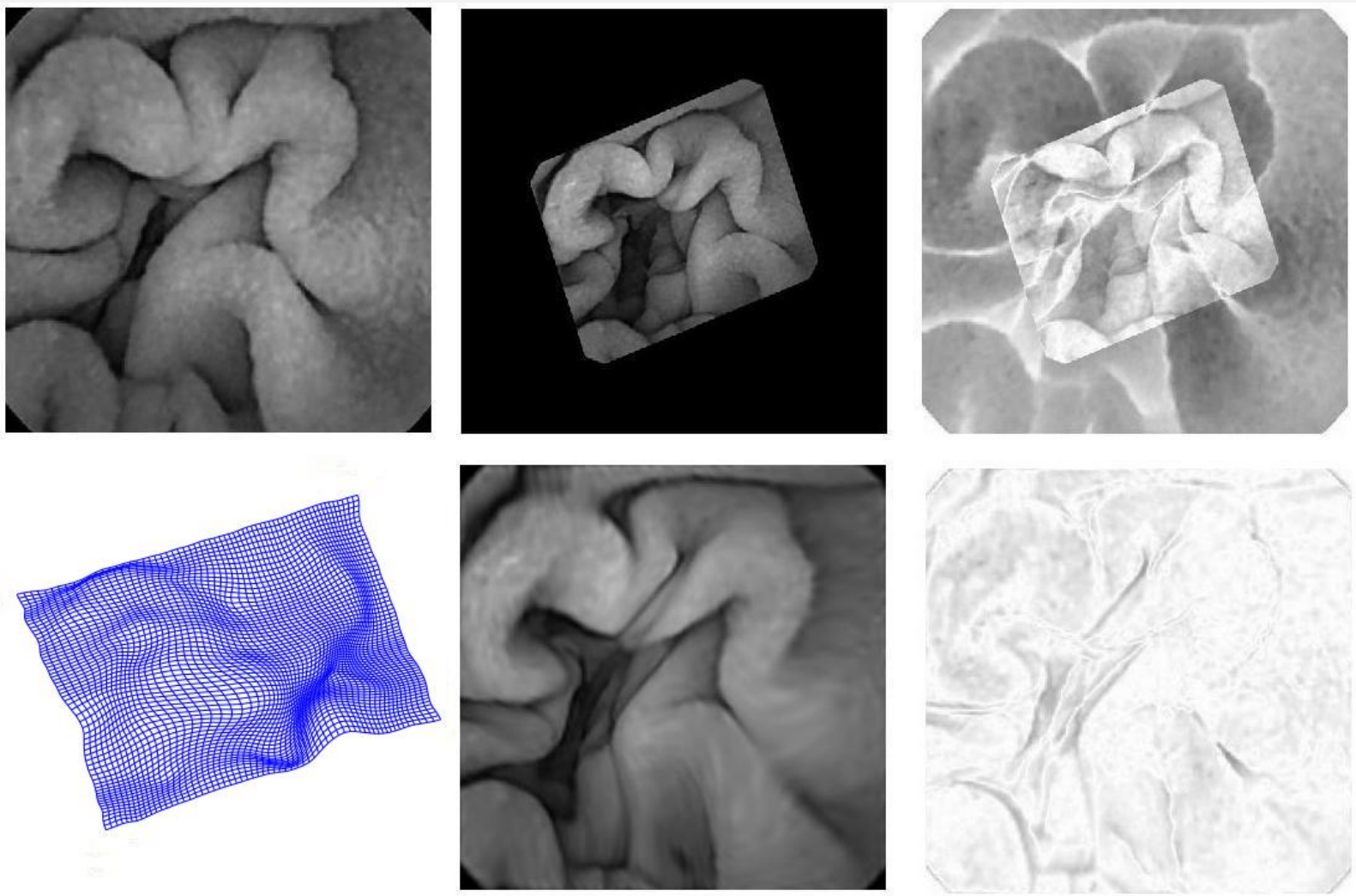
Given consecutive frames T and R, find

$$u \rightsquigarrow \text{Pre-Affine} + \text{Elastic registration (Multiscale)}$$

Scale s estimation, find

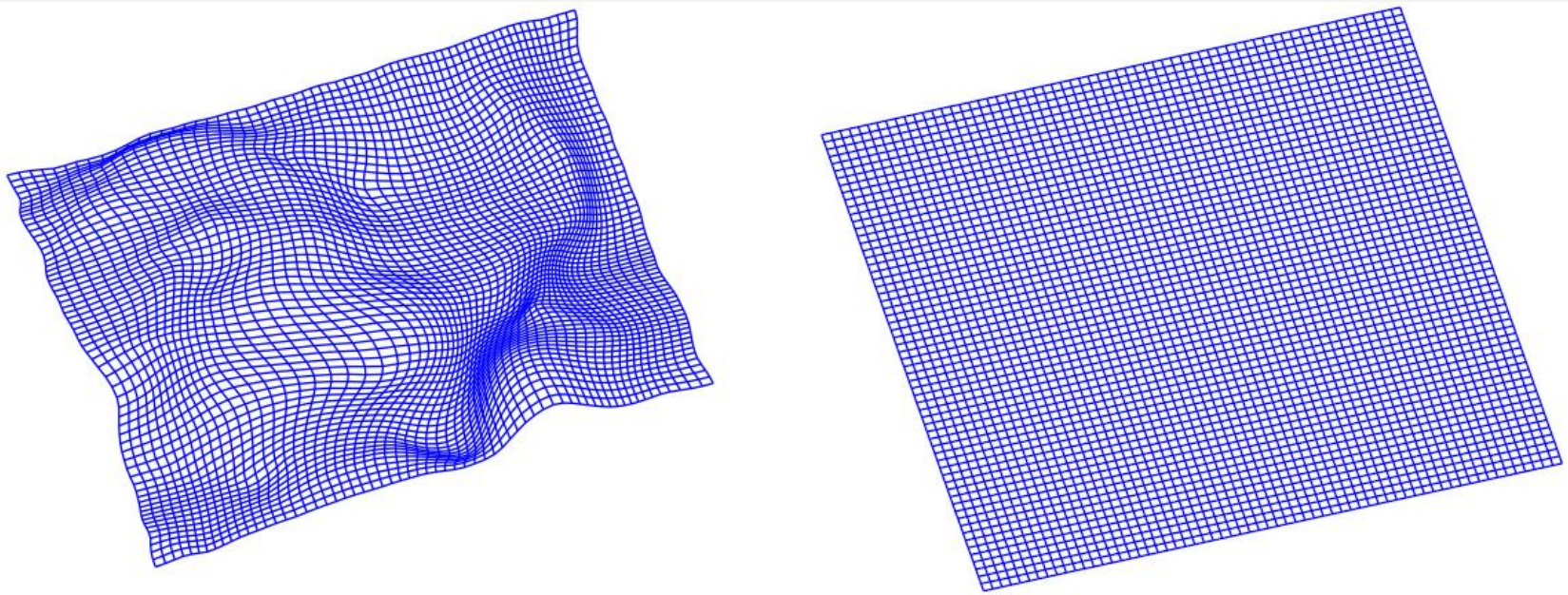
$$u_{affine} \rightsquigarrow min \left\| u_{affine} - u \right\|$$

Motion Estimation



Top, left to right: R, T, and |R-T|. Bottom, left to right: u, T(u), and |R-T(u)|

Motion Estimation



Left to right: transformation u and u_{affine}

- $s \approx 0.55209$

Future Work

Improve the image registration process:

- include spatial information $(\nabla T(u), \nabla R)$
- viscoelastic regularization $S(u)$

More realistic camera modeling:

- lens distortion

Deal with abrupt changes:

- Kalman filter

References

[1] G. Iddan, G. Meron, A. Glukhovsky, P. Swain. Wireless capsule endoscopy. Nature, 405(6785):417-417, 2000.

[2] I.N. Figueiredo, S. Kumar, C. Leal, P.N. Figueiredo. Computer-assisted bleeding detection in wireless capsule endoscopy images. Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization, 1(4):198-210, 2013.

[3] Y. Ye, P. Swar, K. Pahlavan, K. Ghaboosi. Accuracy of rss-based rf localization in multi-capsule endoscopy. International Journal of Wireless Information Networks, 19(3):229-238, 2012.

[4] J. Modersitzki. FAIR: flexible algorithms for image registration, volume 6. SIAM, 2009.

[5] E. Spyrou, D. Iakovidis. Video-based measurements for wireless capsule endoscope tracking. Measurement Science and TechnologyEmail, 25(1), 2014.

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Thank you!