Towards Stiffness Sensors for Minimally Invasive Surgery

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ICRA 2017 Workshop on Innovative Haptic Interfaces
Emerging from Soft Robotics

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Outline

- Motivation
- Vision-based Stiffness Sensing Mechanism
- Multi-directional Stiffness Sensor for Medical Palpation
- Clip-on Stiffness Sensor for Endoscopic Camera
- Conclusion

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Motivation

- Tactile information is crucial in the early stage of diagnosis;
- The outcomes of manual palpation procedures are subjective and limited to the area reachable with the human hands;
- An objective in-vivo measurement technique for assessing the material properties of soft tissue is still missing and will definitely be a valuable tool in diagnosing pathologies.

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Haptic

Haptic or kinesthetic communication recreates the **sense of touch** by applying forces, vibrations, or motions to the user.

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Research Problem

Aim	Soft tissue stiffness estimation
Approach	Development of a stiffness sensing mechanism
Sensing Principle	Stiffness estimation as function of contact forces
Technique	Vision-based estimation of contact forces

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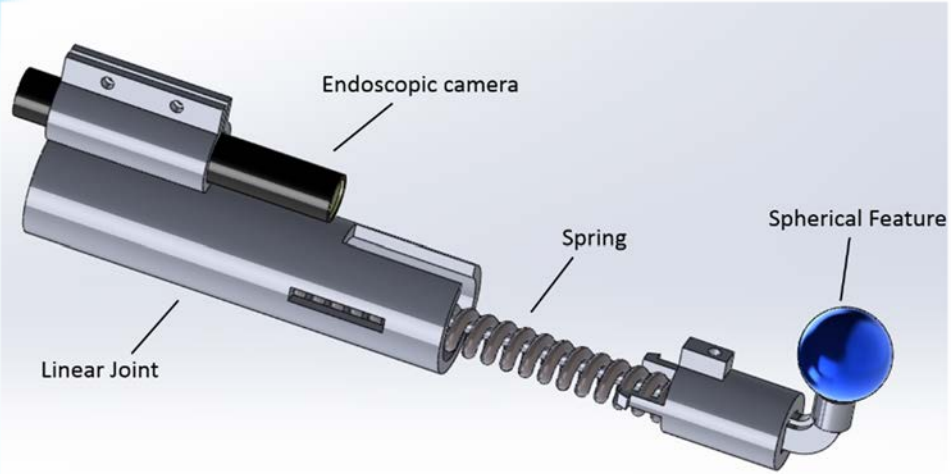
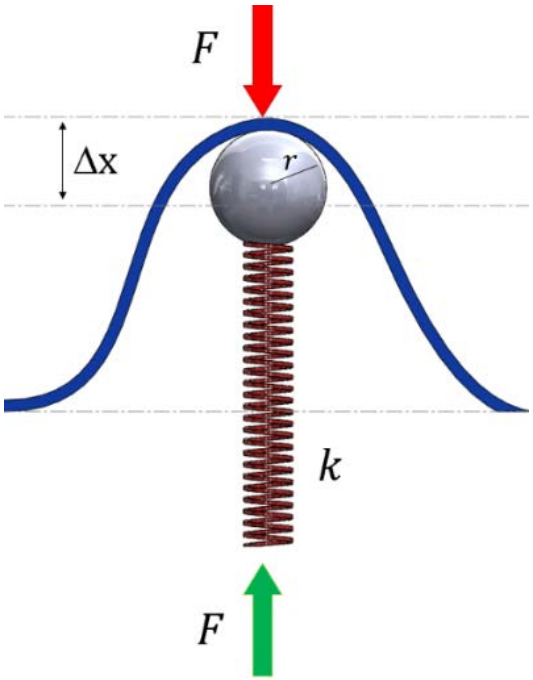
Mechanical Principle

Vision-based Force Sensor





The distance between the sphere and the camera varies with the interaction force.

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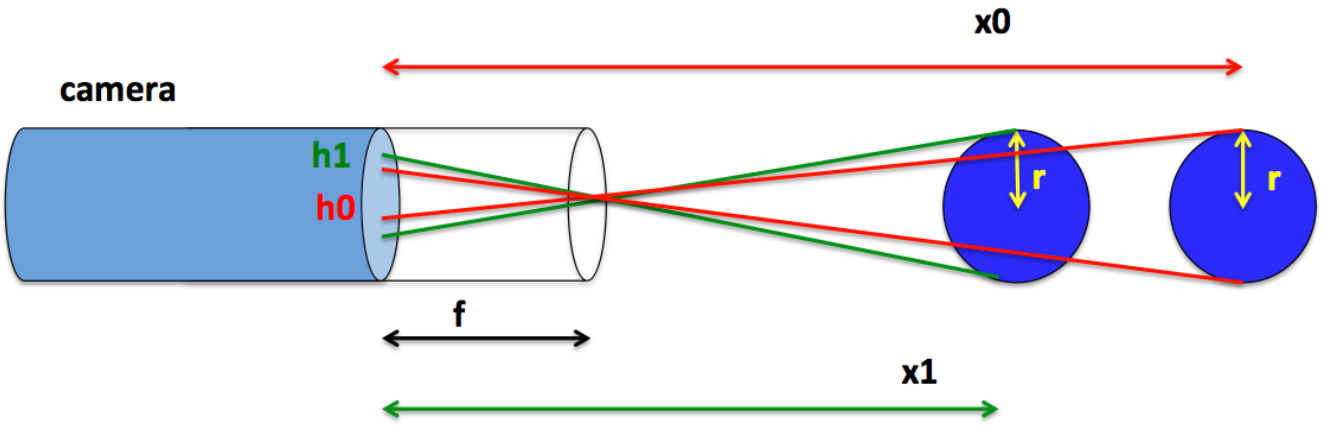
Vision-based Force Sensor

Mathematical Model



A mathematical model computes the force as a function of the feature's radius.

$$F(r) = K\Delta x = k\, x_0(1 - \frac{r_0}{r})$$

* Faragasso A. et al. "Novel uniaxial force sensor based on visual information for minimally invasive surgery", ICRA, 2014.

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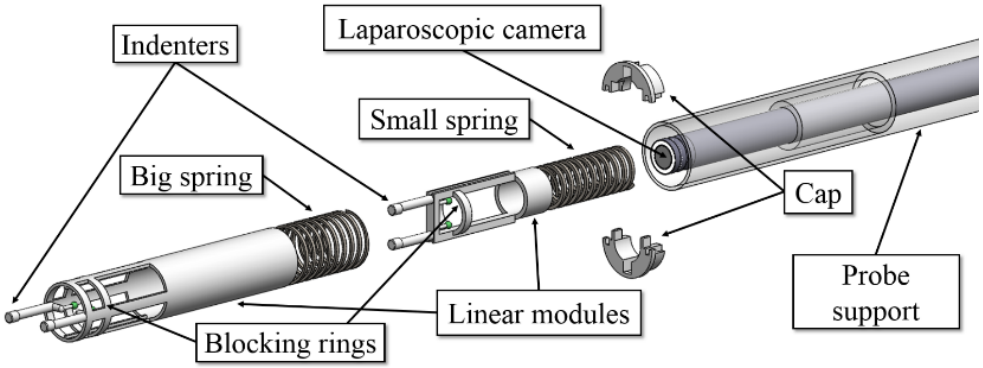
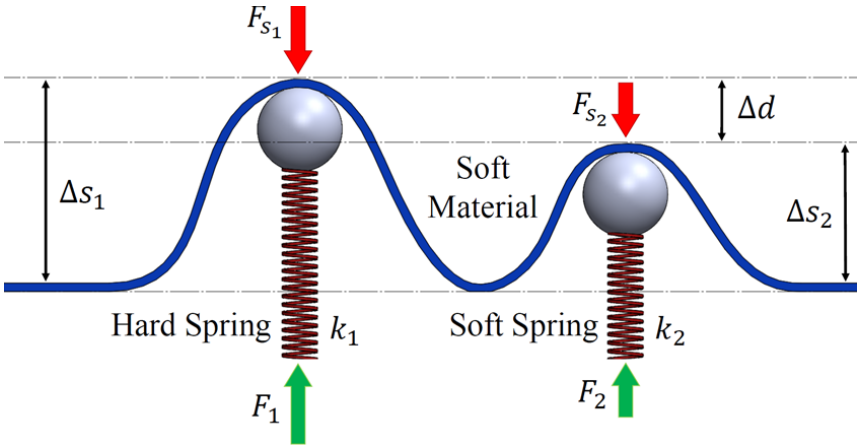
Mechanical Principle

Vision-based Stiffness Sensor





$$K_s = \frac{F_1 - F_2}{\Delta s_1 - \Delta s_2} = \frac{K_1 \Delta x_1 - K_2 \Delta x_2}{\Delta d}$$

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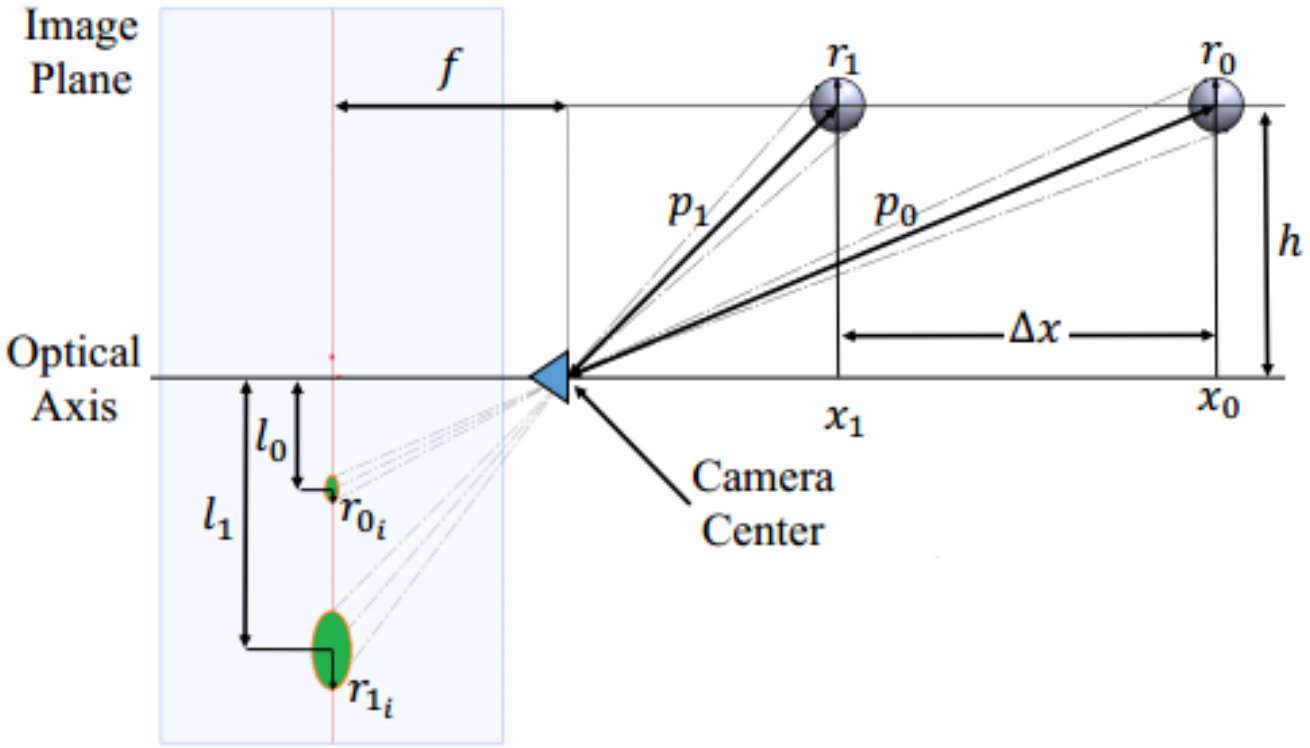
Mathematical Model

Vision-based Stiffness Sensor



$$F(r) = K\Delta x(r) = K\left(x_0 - \sqrt{\frac{r_0^2}{r^2}p_0^2 - h^2}\right)$$

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Stiffness Estimation of Silicon Phantoms

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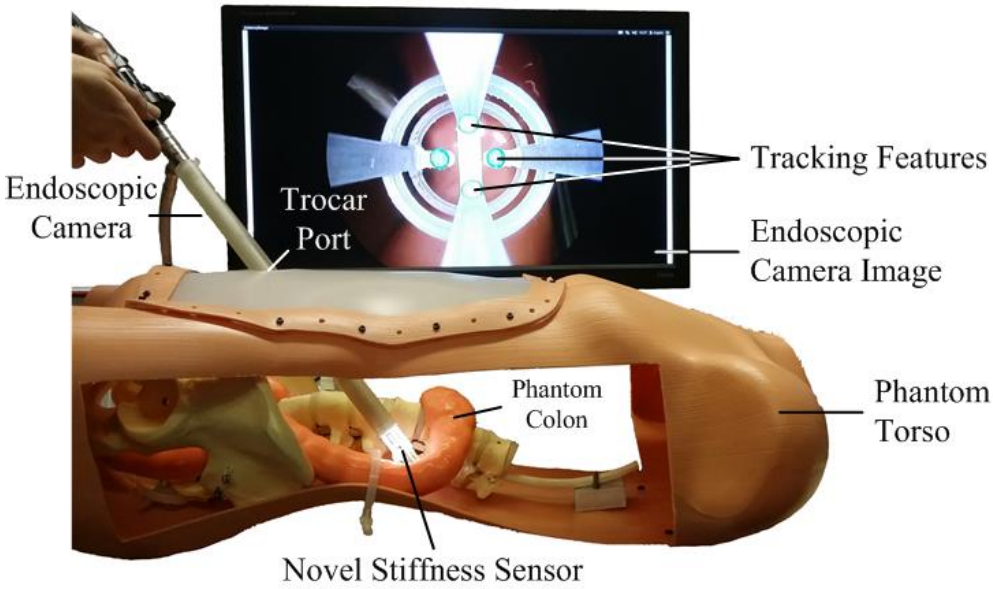
Vision-based Stiffness Sensor



Stiffness material (N/m)	Computed Stiffness	Accuracy
0.085	0.0859	99%
0.6423	0.6166	96%
1.8946	1.8367	96%
2.2373	2.1424	95%
∞	undefined	100%

*Faragasso A. et al. “Endoscopic Add-on Stiffness Probe for Real-time Soft Surface Characterisation in MIS", EMBC, 2014.

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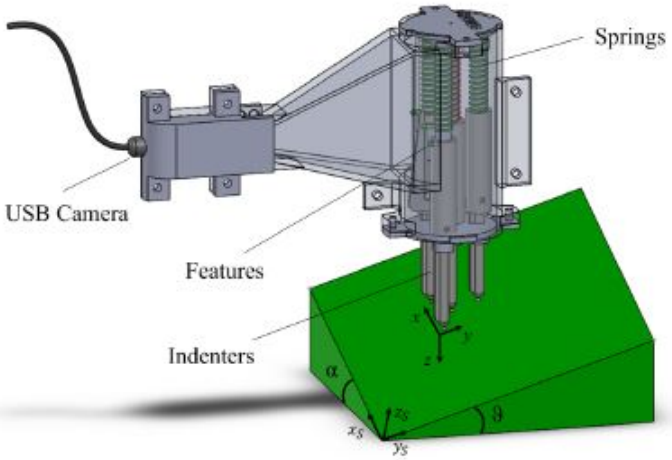
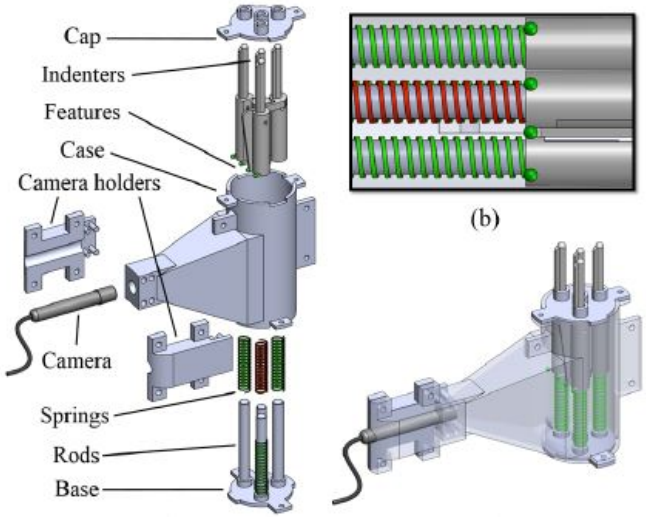
Sensor Design

Multidirectional Stiffness Sensor for Medical Palpation





It comprises four different springs (three soft ones and one that is stiffer).

The displacement of the indenters varies when interacting with a soft object.

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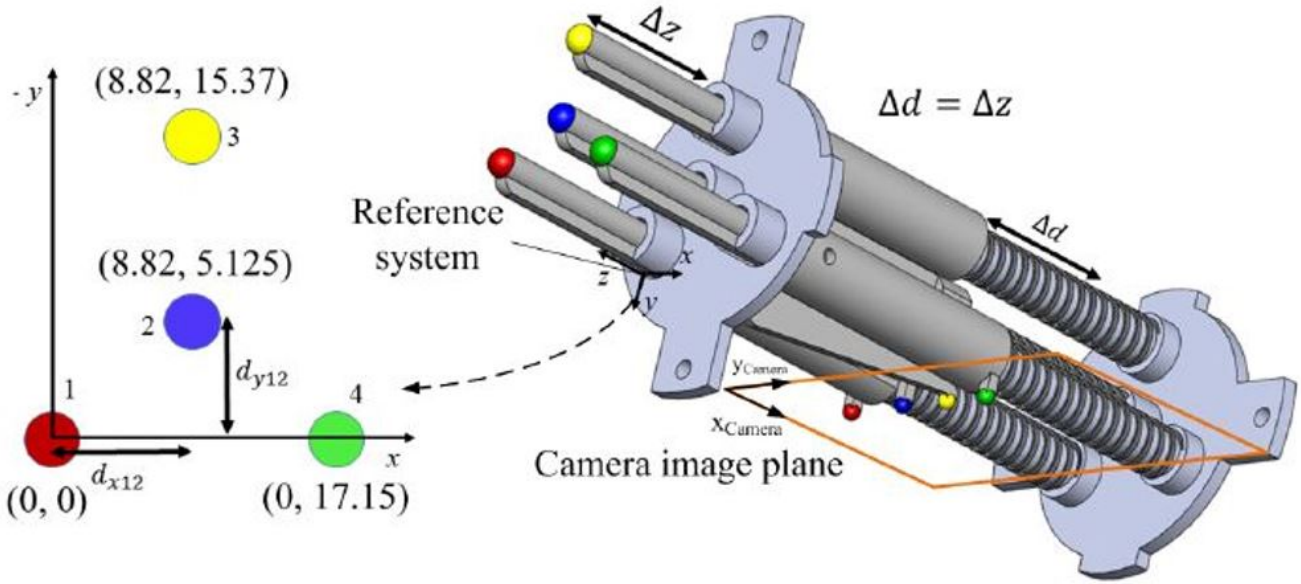
Multidirectional Stiffness Sensor for Medical Palpation

Mechanical Principle



- A mechanism that couples the indenter movements with the movements of spherical features in front of the camera;
- The movements of the features in the image plane $\Delta(x)$, can be used to estimate the movements of the indenters.

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Evaluation Test with Silicon Samples

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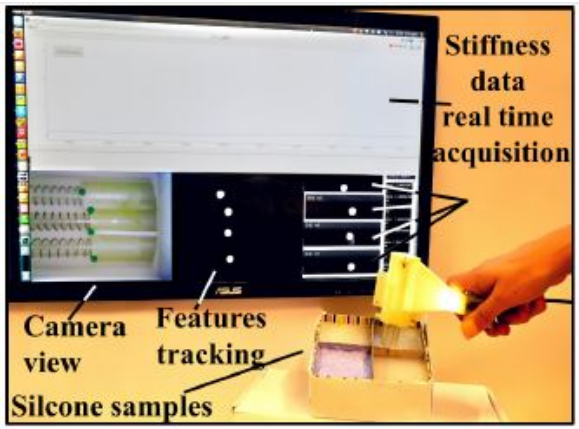
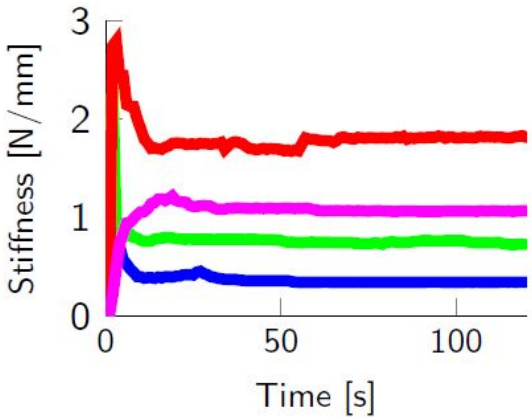
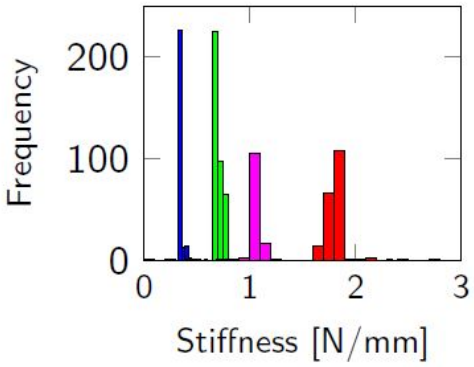
Multidirectional Stiffness Sensor for Medical Palpation



Stiffness evaluation of four different silicon materials





Ecoflex® 00-10 | Ecoflex® 00-50 | Dragon Skin® 20A | Oomoo® 30A

*A. Faragasso et al. "Multi-Axis Stiffness Sensing Device for Medical Palpation", IROS, 2015.

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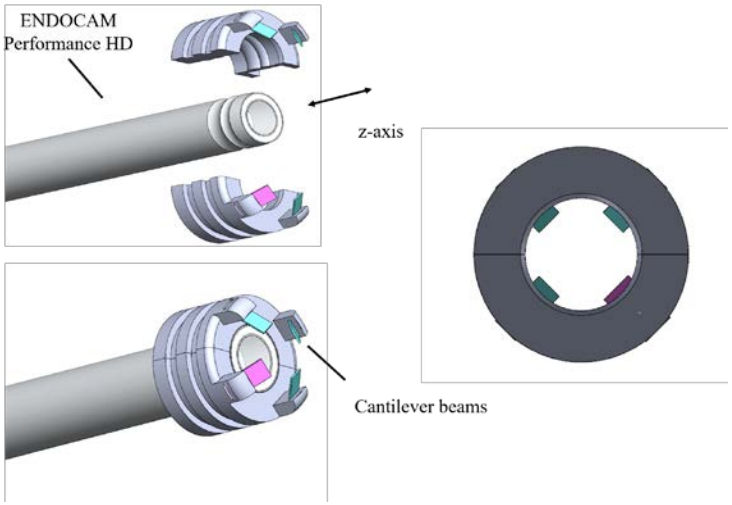
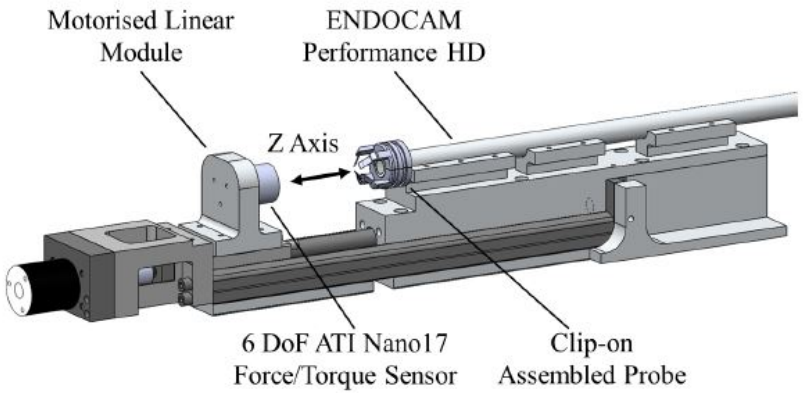
Sensor Design

Clip-on Stiffness Sensor for Endoscopic Camera



- Finite Element of Analysis;
- A calibration device is used to evaluate resolution and force range.



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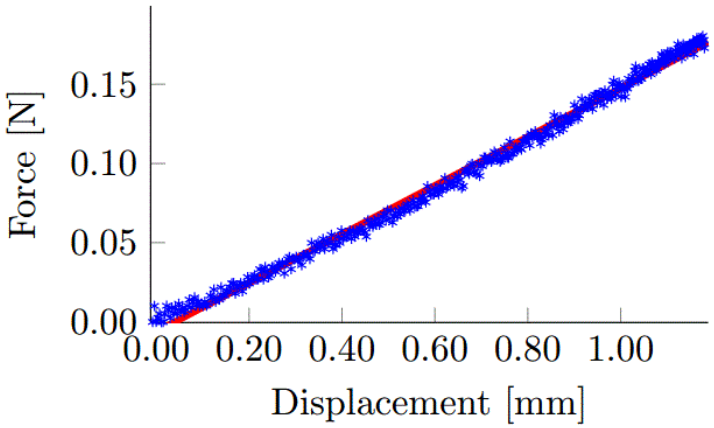
Simulation & Calibration Results

Clip-on Stiffness Sensor for Endoscopic Camera



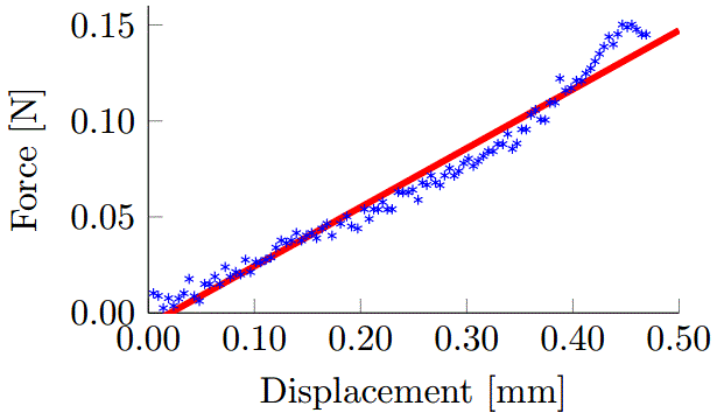


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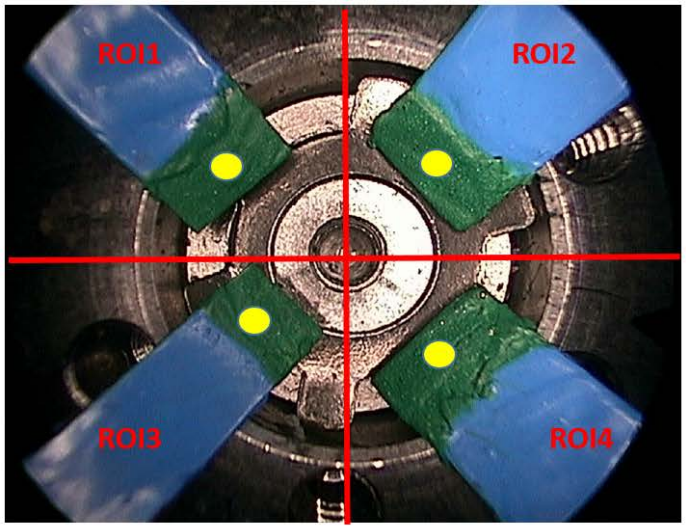
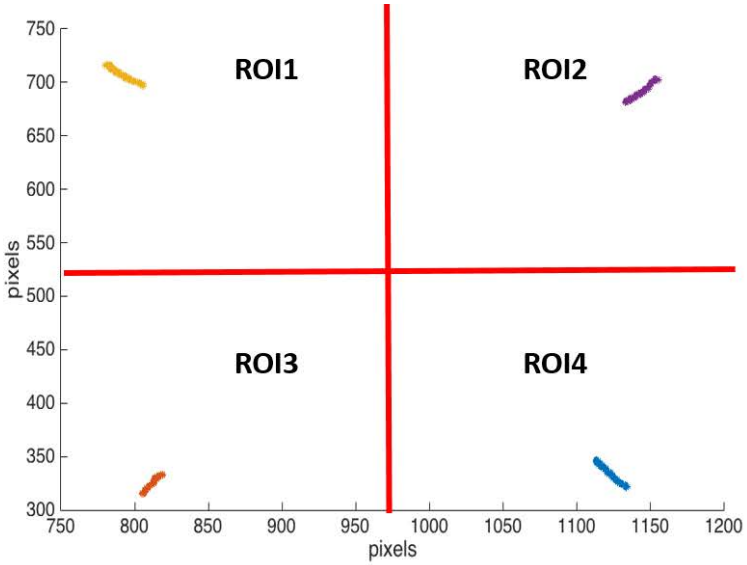
Image Processing

Clip-on Stiffness Sensor for Endoscopic Camera





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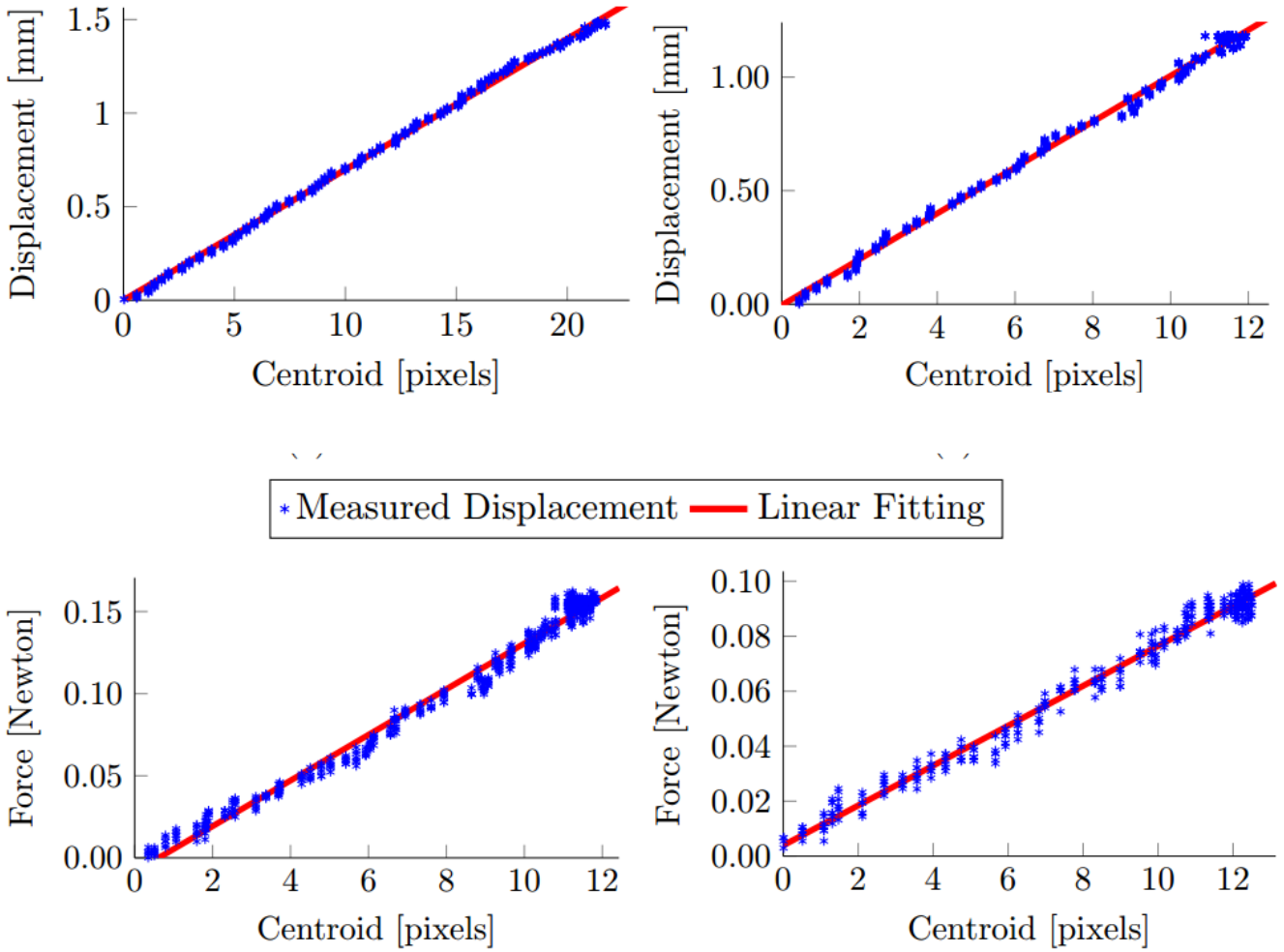
Clip-on Stiffness Sensor for Endoscopic Camera

Evaluation Test Results



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Conclusion

- Development of a sensory mechanism that uses deformable elements and vision to compute forces;

- Real-time stiffness estimation as a function of the relative forces inferred from the deformation of elastic element under load;

- Robust estimation of soft tissue stiffness at different angles.

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Conclusion

THANK YOU FOR YOUR ATTENTION

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