Haptics and Localization of Flexible Instruments in Minimally Invasive Surgery

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Motivation

Haptics and Localzation of Flexible Instruments in Minimally Invasive Surgery

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Position of the tool tip?
Haptic feedback?

Highly Versatile
Single Port System

EndoSnone
Single-Port – DFG Research Group 1321

Prof. Feußner, Prof. Knoll, Prof. Lüth, Prof. Meining, Prof. Rixen, Prof. Ulbrich, Prof. Wörn
Sensors for Flexible Instruments

- Position sensor
  - Measurement of instrument’s shape to determine position of instrument’s tip

- Kinesthetic sensor
  - Push and pull forces at the instrument

- Grip force sensor
  - Grasp forces

Only Fiber Bragg Gratings allow combination of all three types of sensors
Fiber Bragg Gratings

- Glass fibers with locally inscribed optical structures (gratings)
  - Reflected wavelength depends on strain
  - „optical strain gauges“

Broadband Source | Reflected Light | Transmitted Light

Intensity | 

\[ \lambda \] | \[ \lambda_b \] | \[ \lambda \] | \[ \lambda_b - \Delta \lambda \] | \[ \lambda \] | \[ \lambda_b + \Delta \lambda \] | \[ \lambda \] | \[ \lambda_b \] | \[ \lambda \]

Unstrained fiber

Fiber under tensile strain

Compressed fiber
Fiber Bragg Gratings

- Glass fibers with locally inscribed optical structures (gratings)
  - reflected wavelength depends on strain
  - „optical strain gauges“

+ Very thin (Ø 195µm)
+ EMC-compatible
+ Bio-compatible
+ Easy multiplexing (multiple gratings in one fiber)

- Temperature dependency
Shape Sensor
Shape Sensor – Basic Concept

- Detect local bending direction of instrument via fiber strain
  - Three gratings per plane orthogonal to instrument for robustness
- Multiple planes along instrument
- Interpolate the shape of the instrument
Shape Sensor – Form Reconstruction

Strain measurement

Discrete curvature and curvature direction

Continuous functions for curvature and torsion

Calculation of Frenet-frame

Curve progression of central axis

\[ K(s) = \int_{0}^{s} T(\sigma)d\sigma \]

Fiber Bragg Grating

\[ T(s) = \kappa(s)N(s) \]

\[ N'(s) = -\kappa(s)T(s) + \tau(s)B(s) \]

\[ B'(s) = -\tau(s)B(s) \]
Shape Sensor - Construction

- Cast three fibers with gratings in flexible material

Silicone
Not optimal because fibers start sliding

Length: 180 mm
Ø: 3 mm

ORMOCER®
Fraunhofer ISC
Haptic Sensors

Kinesthetic Sensor

Grip Force Sensor

F

F

F
Kinesthetic Sensor

- Stewart-Platform
- Measurement of force and torque (6 DOF)
- FBGs are integrated into the structure
Grip Force Sensor

- Transducer structure with Fiber Bragg Grating
- Force onto the sensor → fiber is stretched
Haptic Feedback

Tactile Display

Haptic Display
What does the Surgeon Need to Feel?

- Collisions, forces on tissue or on thread during suturing
- **Force feedback** via input device

- Surfaces, bumps, structures inside soft tissue like blood vessels or tumors
- **Stimulation of skin** via tactile display

**Challenge:** Merge both sensations into one device

- Small but powerful tactile display required
- Limitations by hardware → focus on software
Tactile Display

12 pins
- diameter: 1 mm
- distance: 1 mm
- area: 5 x 7 mm²
- amplitude: 4 mm
- resolution: 0.03 mm

12 DC motors
Graupner DES 478 BB MG
- speed: ~0.09 s for 4 mm
- force per pin: 30 N
How does it Work?

- Surgeon scans sensor data with input device
- Finger rests on the tactile display
How does it Work?

- Demo with sample data in Matlab-GUI
  - Images replace sensor data (height maps)
  - Mouse is used as input device
Haptic Display

- Simulation of palpation of soft tissue

Haptic phantom:
- no force
- global deformation
- global + local deformation

Haptic display:
- no feedback
- force feedback
- force and tactile feedback

16.04.2014

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Haptic Display

- Spring-loaded pins, servo motors to increase pre-stress
- Functional prototype with single pin
- Currently construction of seven pin setup
Conclusion/Future Work

- Shape and haptic sensors based on Fiber Bragg Gratings
  - Goal: entire sensor system with three fibers
- Tactile sensor for palpation of soft tissue

- Two devices with different scope for haptic stimulation
  - Goal: flexible link between motors and pins for miniaturization
- Tool with grip force feedback

![tactile sensor](image1)

![pneumatic pin display](image2)

![grip force feedback](image3)
Thank you for your attention.