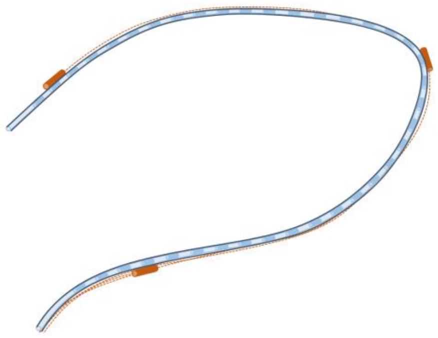
3D CATHETER GUIDANCE INCLUDING SHAPE SENSING



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GEFÖRDERT VOM
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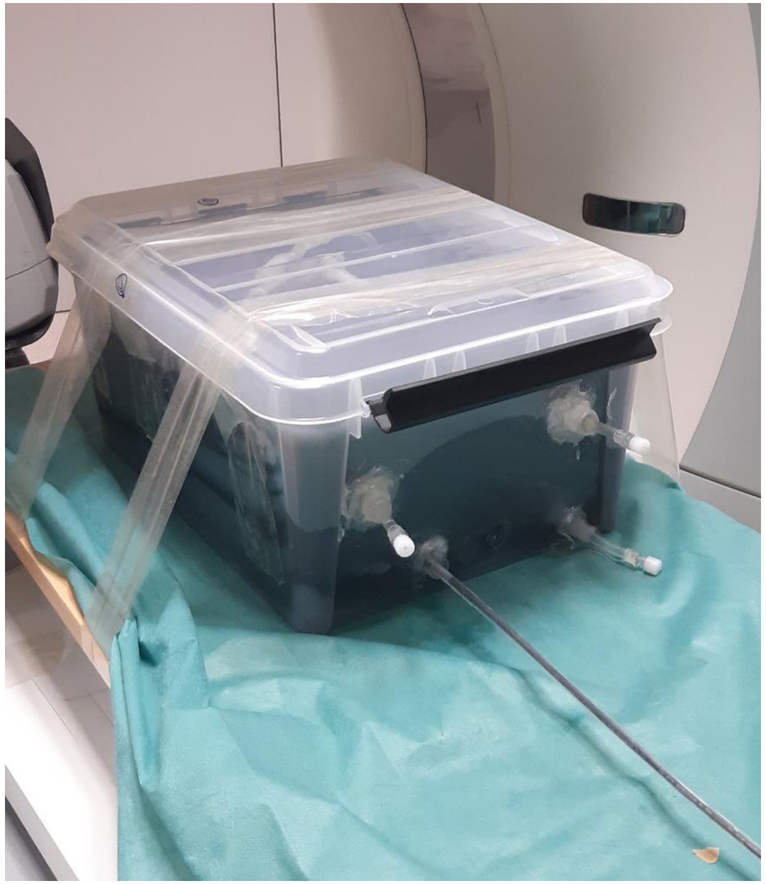
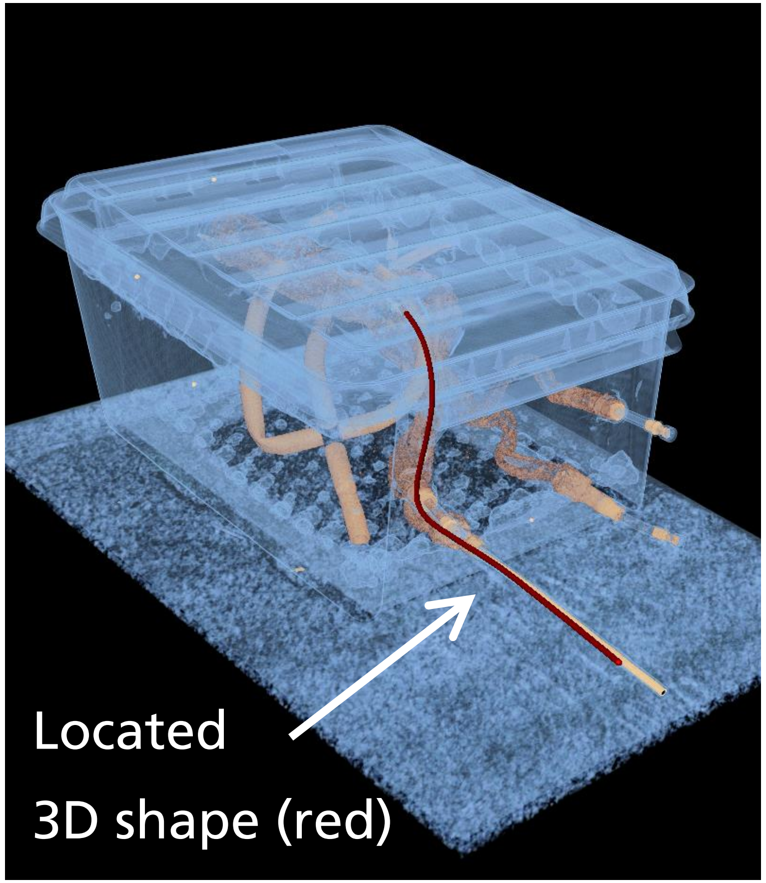
Motivation – catheter guidance

View in real world

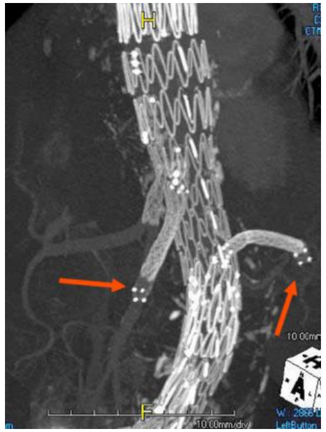


CT scan view



Motivation – clinical problem

- Use case: vessel repair by implanting a stentgraft



- Current guidance of instruments: 2D fluoroscopy with contrast agent
  Drawbacks:
  - Radiation exposure of surgical team and patient (Rehani et al. 2006)
  - Contrast agent is kidney damaging (Saratzis et al. 2015)
  - Missing depth information leads to challenging navigation

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Motivation – goal and idea

- Goal: 3D catheter guidance without the use of X-ray and contrast agent
- Idea:

Fiber optical shape sensing

✓ Shape

X Location

+

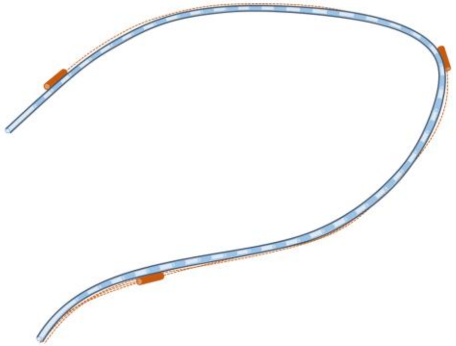
Electromagnetic (EM) tracking

X Shape

✓ Location

=

3D catheter guidance

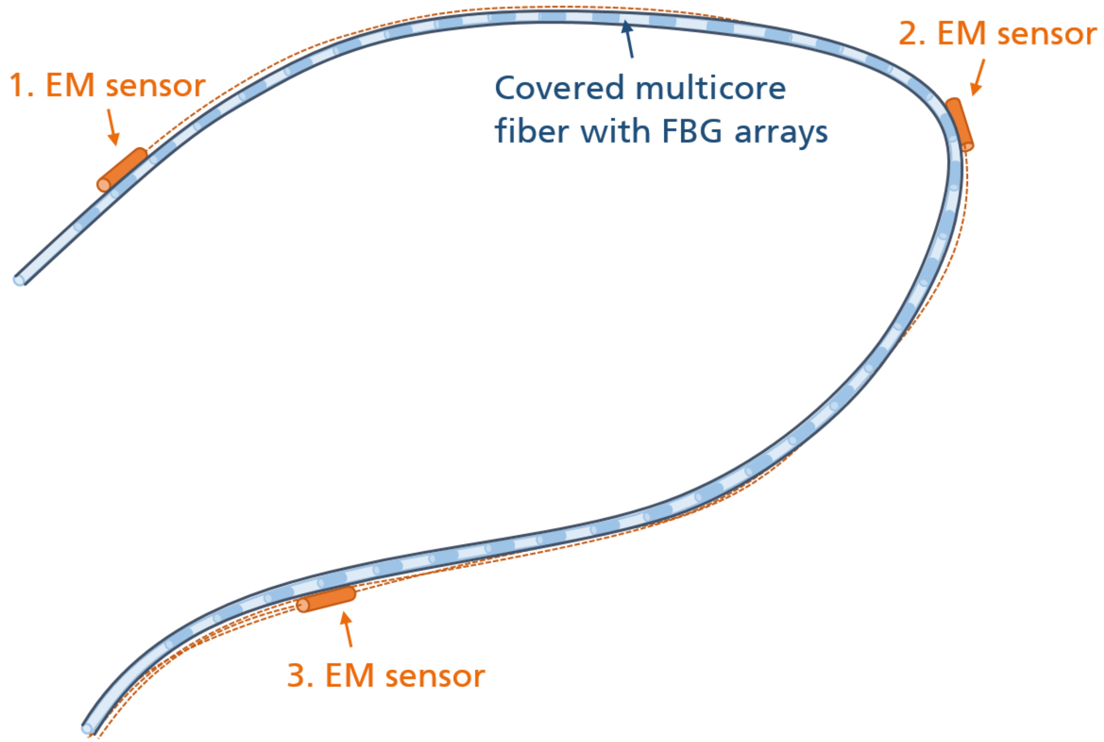


✓ Shape

✓ Location

Catheter prototype

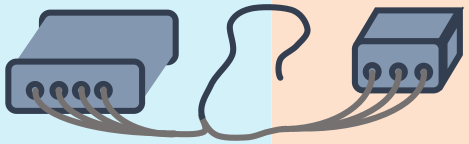
- Prototype containing:
  - Multicore fiber with 38 fiber Bragg gratings
    → **Optical fiber, which allows shape sensing**
  - 3 EM sensors at the tip, middle and end of the shape sensing region
    → **Position and orientation information**



Guidance Method – model

Fiber optical shape sensing

Measured wavelengths



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Shape reconstruction with fiber optical shape sensing

Electromagnetic tracking

Three measured EM poses

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Transformation to CT space with metallic markers

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Shape localization using results of the spatial calibration

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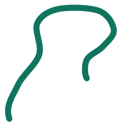
3D catheter guidance

Located shape of the catheter in the CT space

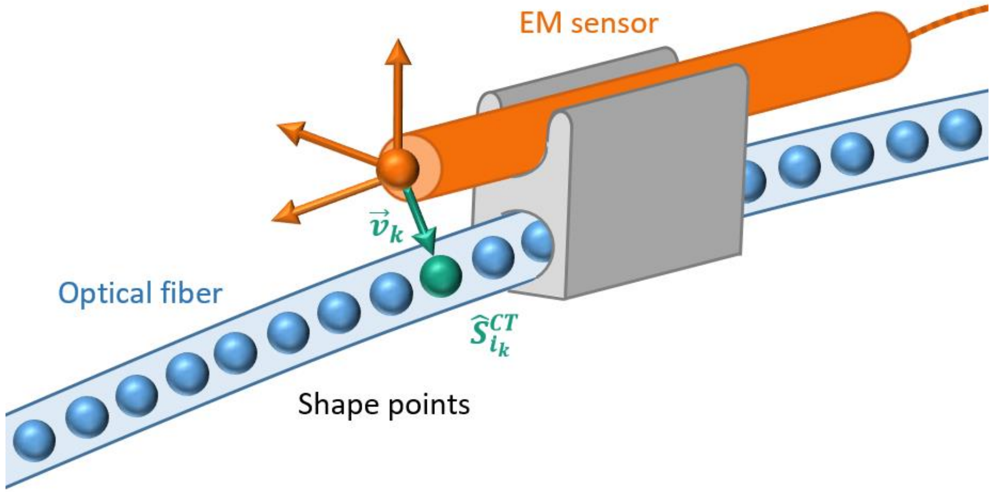


Guidance Method – spatial calibration

- Goal: Find spatial correspondence between **optical fiber** and **each EM sensor**.

- One experiment with tracking data and CT scan with segmentations needed

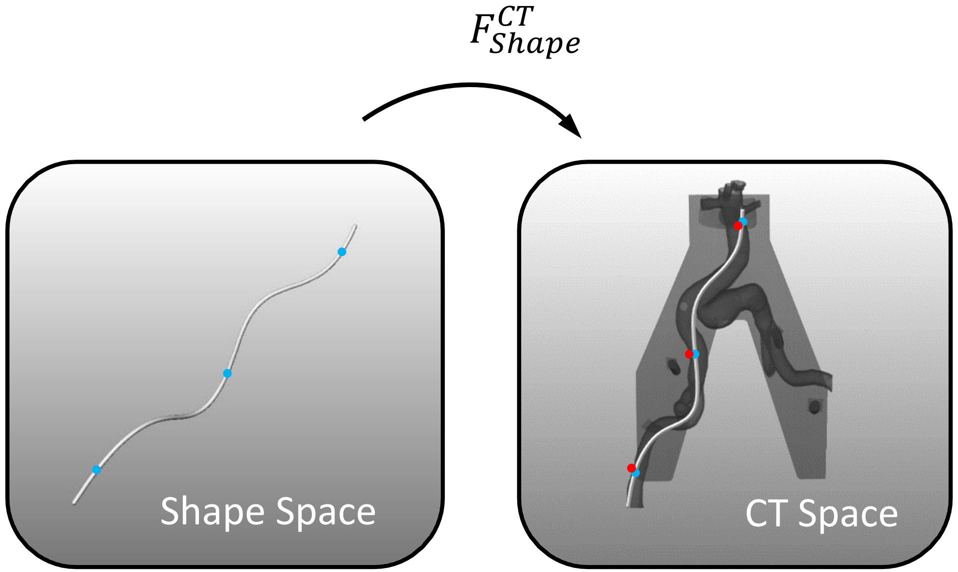
- Spatial relation:
  - Determination of **corresponding shape point $\hat{S}_{i_k}^{CT}$**.
  - Calculation of **correction vector $\vec{v}_k$** to map the EM sensor position to the corresponding shape point.



Guidance Method – Shape Localization

- Given from tracking system and spatial calibration:
  - Shape points in Shape Space: $\{\hat{S}_{i_1}, \hat{S}_{i_2}, \hat{S}_{i_3}\}$
  - Corresponding EM sensor positions in CT space:

$$\{\hat{T}_1^{CT} + \vec{v}_1, \hat{T}_2^{CT} + \vec{v}_2, \hat{T}_3^{CT} + \vec{v}_3\}$$



- Computation of rigid transformation F_{Shape}^{CT} from shape space in CT space by means of point based registration.
  (Arun et al. 1987)

Experiments

- Evaluation with five different catheter shapes.

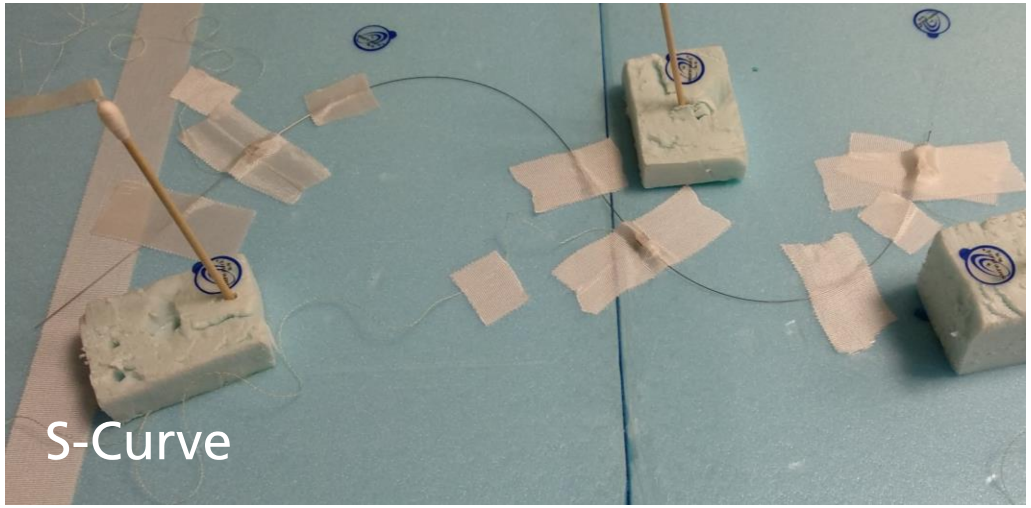
- CT acquisition and the segmentations are used as ground truth.

- Measures:

  average error: $e_{avg} = \frac{1}{m}\sum_{i=1}^{m}\left\|x_i - x_i^{gt}\right\|_2$

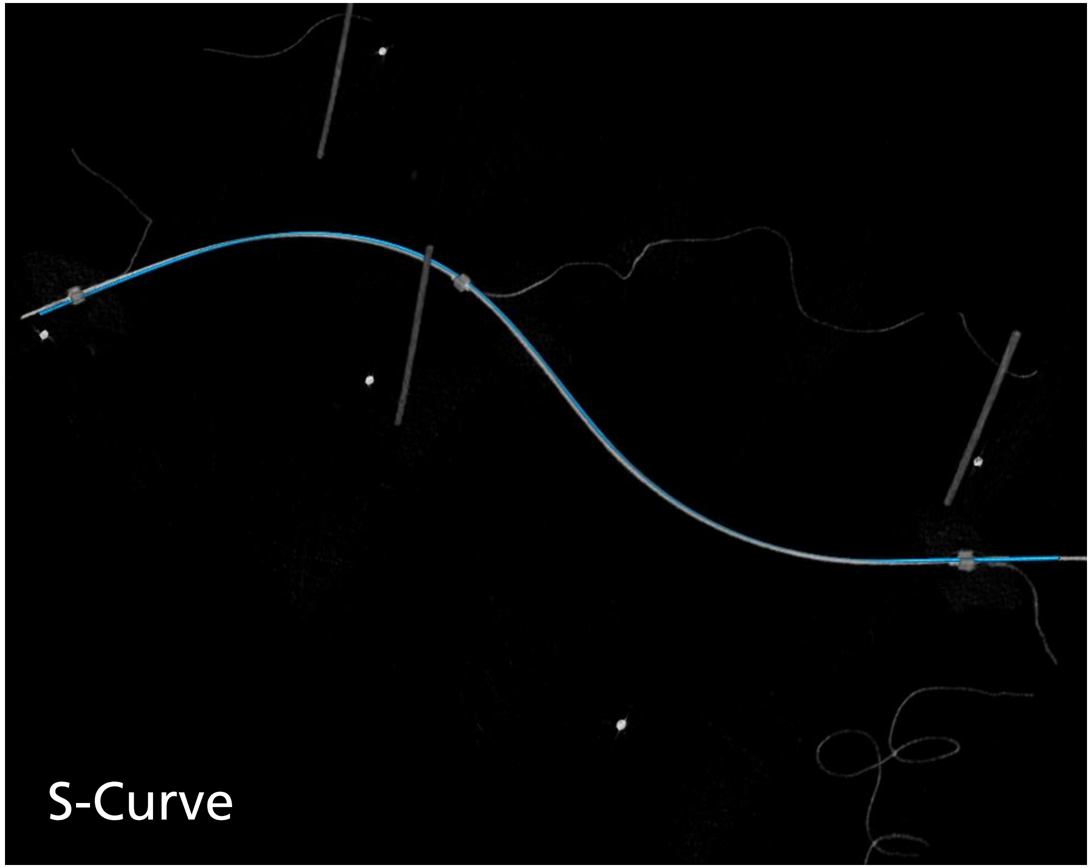
  maximum error:

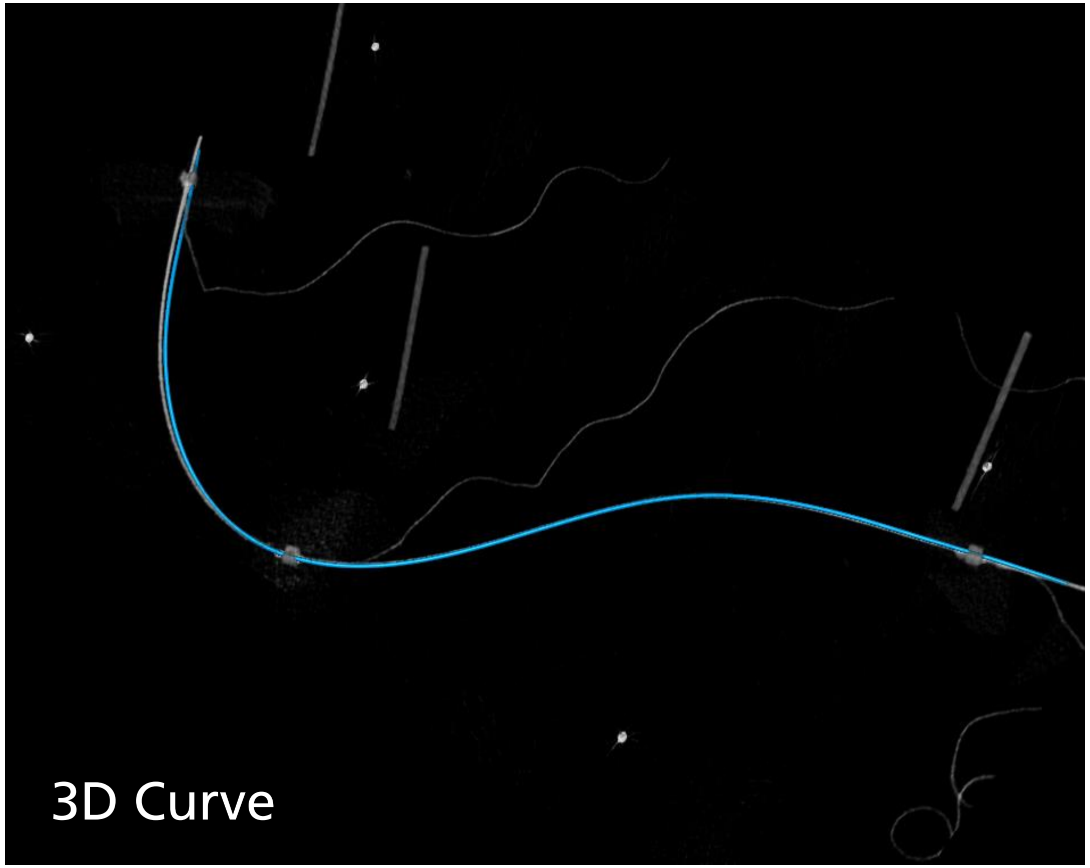
  $$e_{max} = \max\left(\left\|x_1 - x_1^{gt}\right\|_2, \dots, \left\|x_n - x_n^{gt}\right\|_2\right)$$



Results – Located shapes

- 3D CT scan with located shapes (blue):





Results - Accuracies

- Measured errors in mm:

	Reconstructed shape	
		
Shape \ Error	e_{avg}	e_{max}
Bow	0.73	2.19
Curve	0.51	2.05
S-Curve	0.62	2.29
3D Bow	0.90	2.25
3D Curve	0.63	1.01

→ **Comparable to previous experiments**

Results - Accuracies

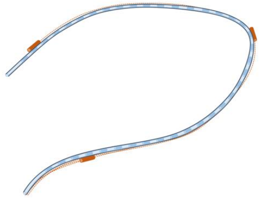
- Measured errors in mm:

Shape \ Error	Reconstructed shape e_{avg}	Reconstructed shape e_{max}	EM sensor positions e_{avg}	EM sensor positions e_{max}
Bow	0.73	2.19	0.85	0.93
Curve	0.51	2.05	0.93	0.99
S-Curve	0.62	2.29	0.65	0.79
3D Bow	0.90	2.25	0.86	1.12
3D Curve	0.63	1.01	0.72	0.92

→ **Comparable to experiments from literature**

Results - Accuracies

- Measured errors in mm:



Shape \ Error	Reconstructed shape		EM sensor positions		Located shape	
	e_{avg}	e_{max}	e_{avg}	e_{max}	e_{avg}	e_{max}
Bow	0.73	2.19	0.85	0.93	0.99	2.60
Curve	0.51	2.05	0.93	0.99	1.10	1.73
S-Curve	0.62	2.29	0.65	0.79	1.55	2.45
3D Bow	0.90	2.25	0.86	1.12	2.29	2.99
3D Curve	0.63	1.01	0.72	0.92	1.15	1.90

Reconstructed shape + EM sensor positions = Located shape

Conclusion

- A first catheter prototype with a multicore fiber and three EM sensors

- **A novel 3D catheter guidance method**
  → Accurate located shapes

- Future work:
  - Guidance method with less EM sensors
  - Evaluation in a realistic setting