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A Stereoscopic Fibroscope for Camera Motion and 3D Depth Recovery during Minimally Invasive Surgery

David Noonan, Peter Mountney, Daniel Elson,
Ara Darzi and Guang-Zhong Yang

Institute of Biomedical Engineering & Dept. of Biosurgery & Surgical Technology
Imperial College London

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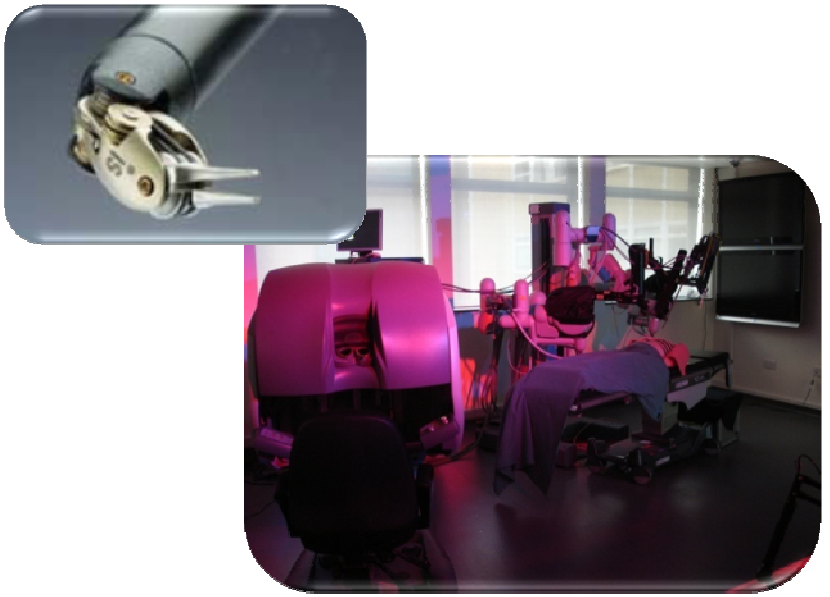
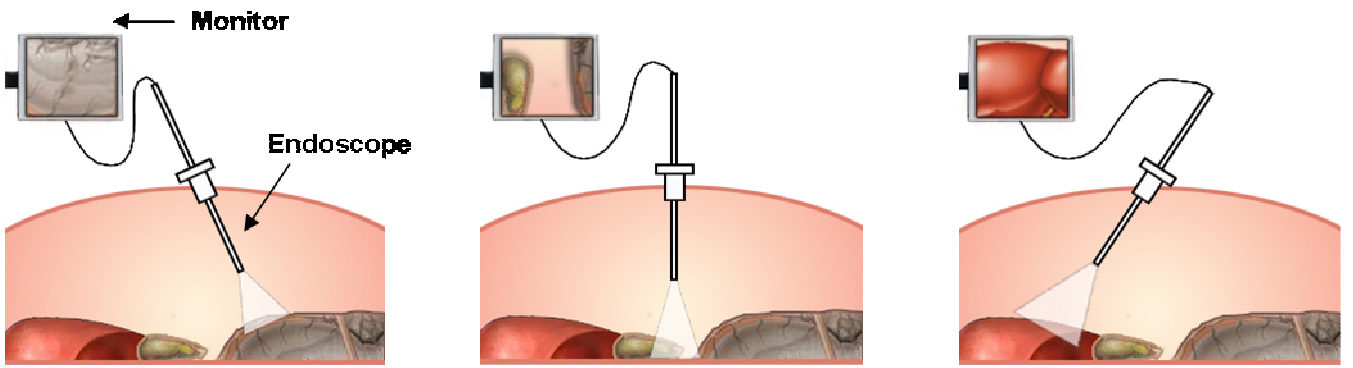
RobotsSLAM in Minimally Invasive Surgery

- Use of robotic surgery systems increases
- Scope exists to enable ever more complex procedures
- Interventions along curved instrument pathways
- Stereo fibre image guide based system is ideally placed for integration with flexible insturmentation where miniaturisation is required





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Outline

- System design of a Stereoscopic Fibroscope
- SLAM algorithm design
- Validation steps performed
- Results
- Additional capabilities

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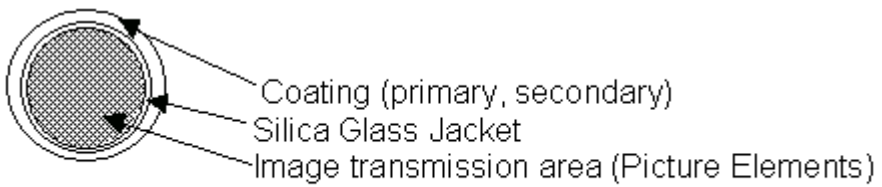
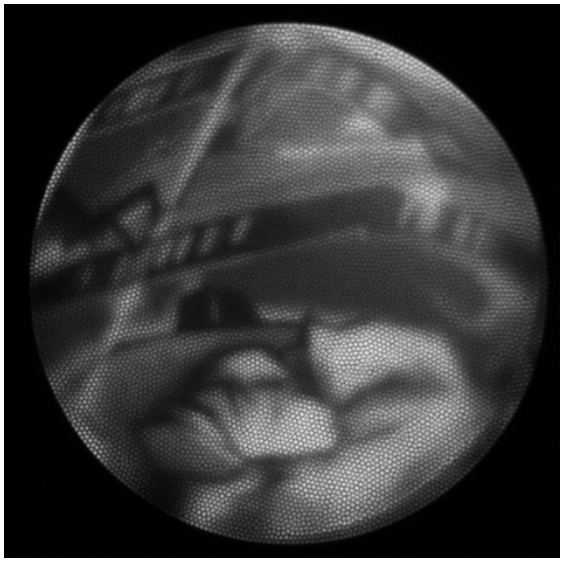
Fibre Image Guides

- Type: Sumitomo IGN-05/10 coherent fibre image guide
  - Pixels: 10,000
  - Length: 1.5mm
  - Diameter: 590µm
  - Min. bending radius: 25mm
- GRIN lens cemented to each tip
  - Image area: 35x35mm^2
  - Working distance 20mm



[Cross Sectional View of Image Guide Fiber]



Number of picture elements	10000
Jacketing diameter (um)	500
Picture elements area diameter (um)	450
Coating diameter - primary (um)	590
Coating diameter – secondary (um)	---
Circularity	>/=0.93
Core material	GeO2 containing silica
Cladding material	F containing silica Silicone
Coating material	Silicone
Numerical aperture	0.35
Lattice defect (%)	</=0.1
Allowable bending radius	25
Allowable max temp (℃)	150

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Stereoscopic Fibroscope

1. Passive 3-axis joint to facilitate free-hand motion
2. Rigid body to mount optical tracking markers
3. Protective tubing for fibre image guides
4. 2 * 10,000 flexible fibre image guide
5. Grubscrew to adjust camera vergence
6. Tubing path to image acquisition system

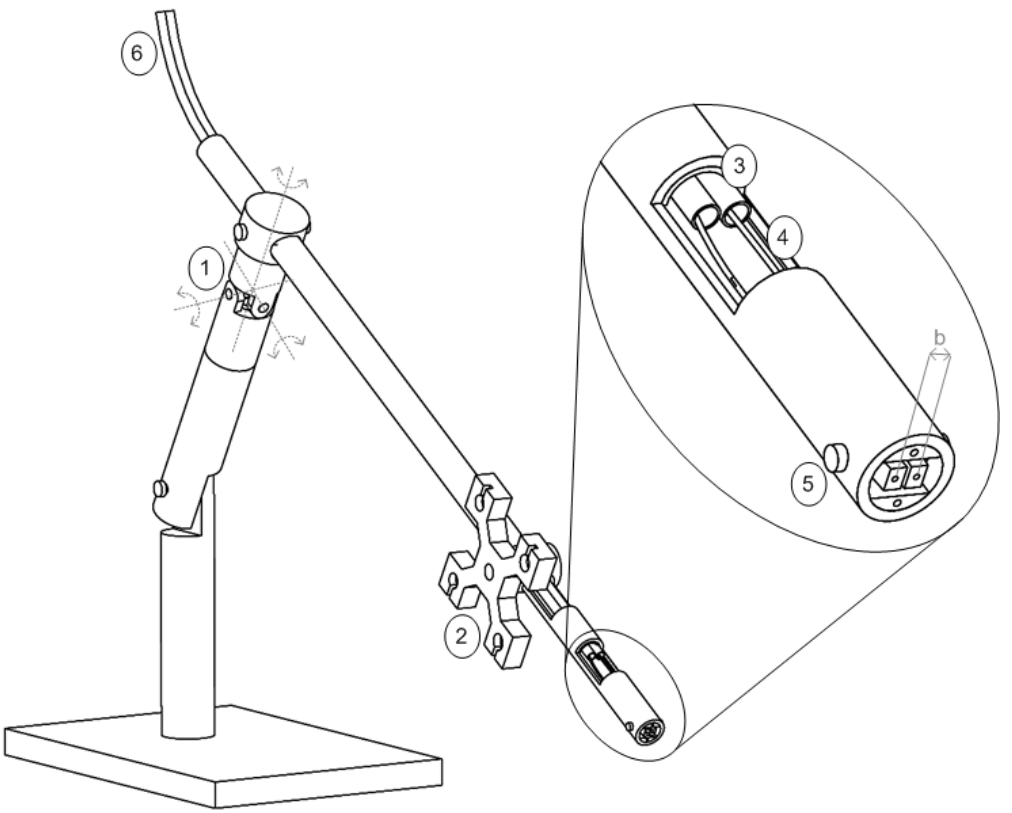

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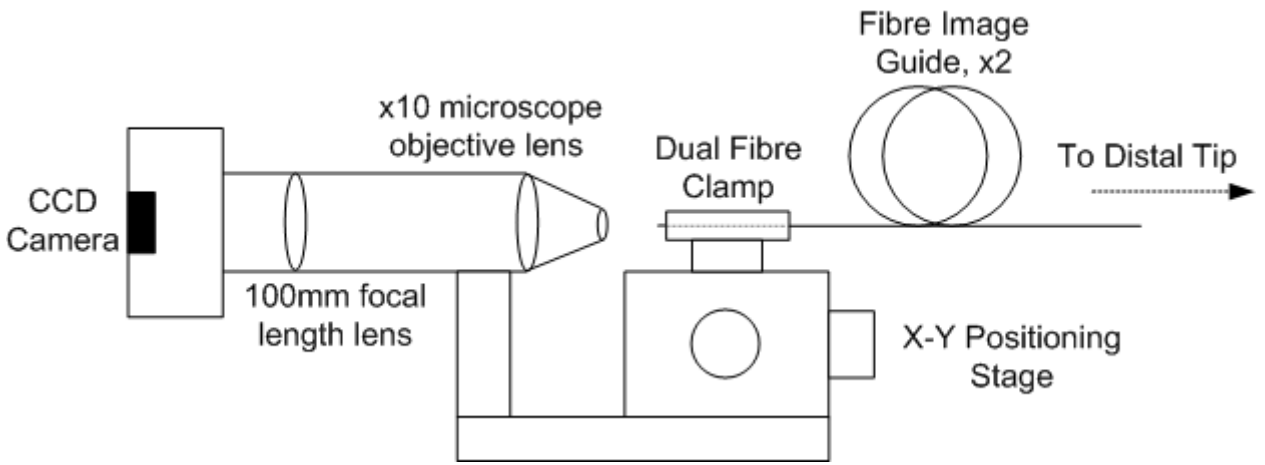
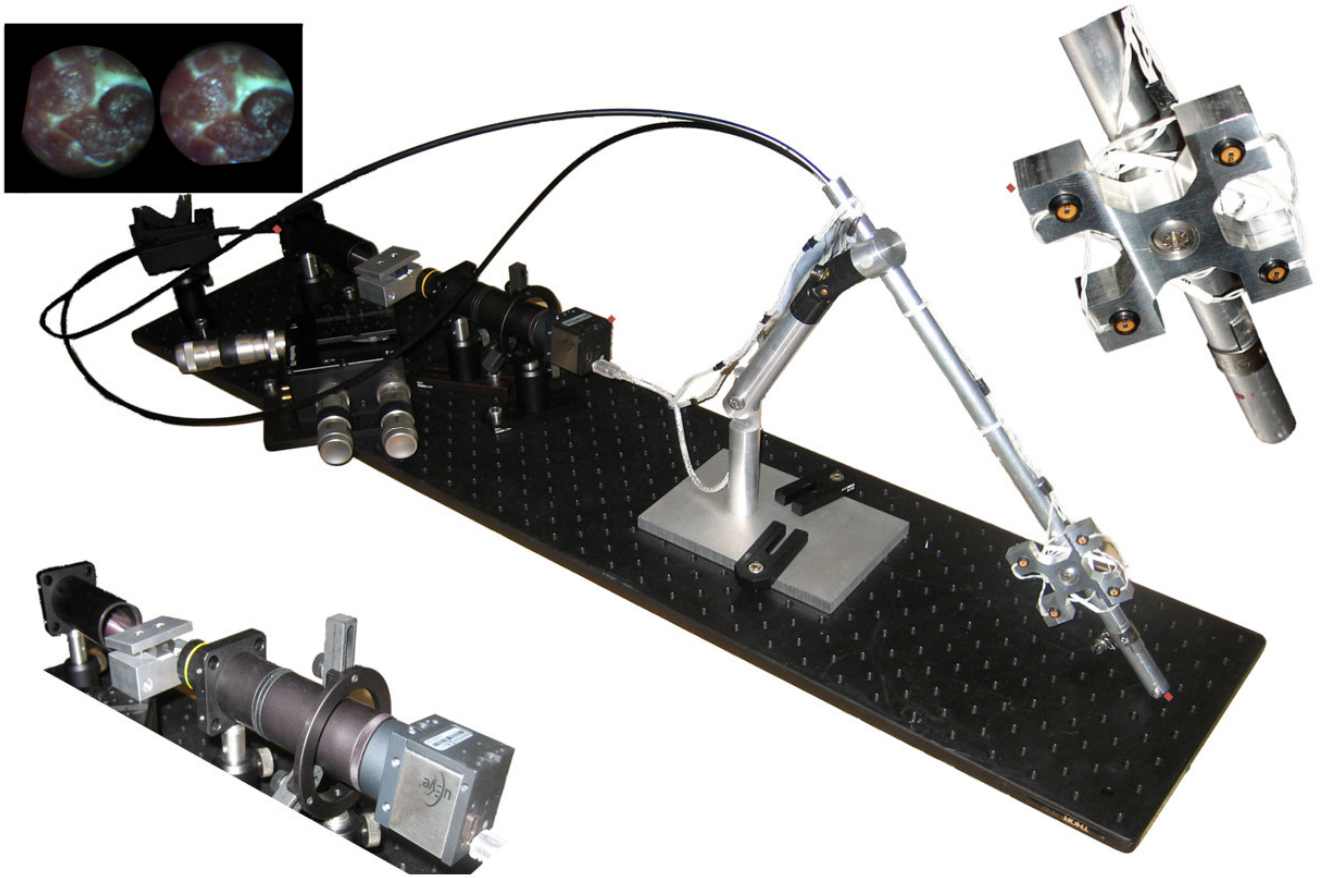
Image Acquisition System

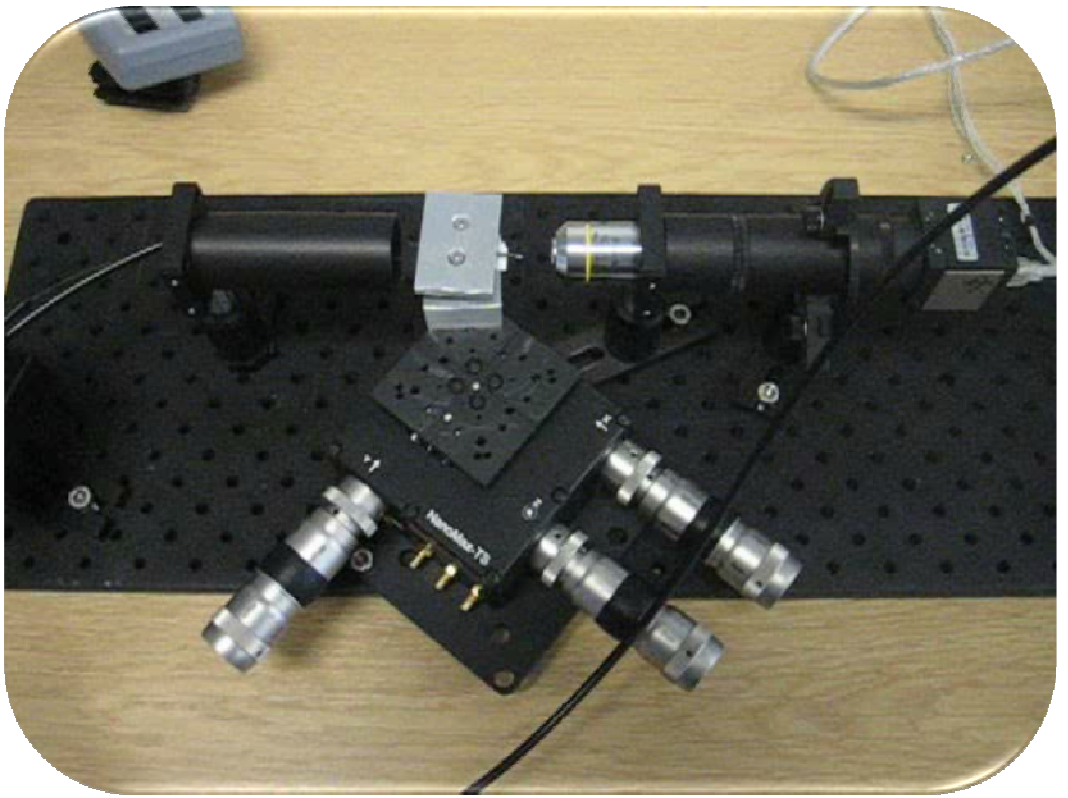


- Acquisition via:
  - CCD Camera: UEye, UI-2250-C/CM
  - Both images focussed onto a single camera
  - X10 achromatic microscope objective
  - 100mm focal length lens
  - XYZ positioning stage
  - Custom fibre mount

Full System



Full System (2)



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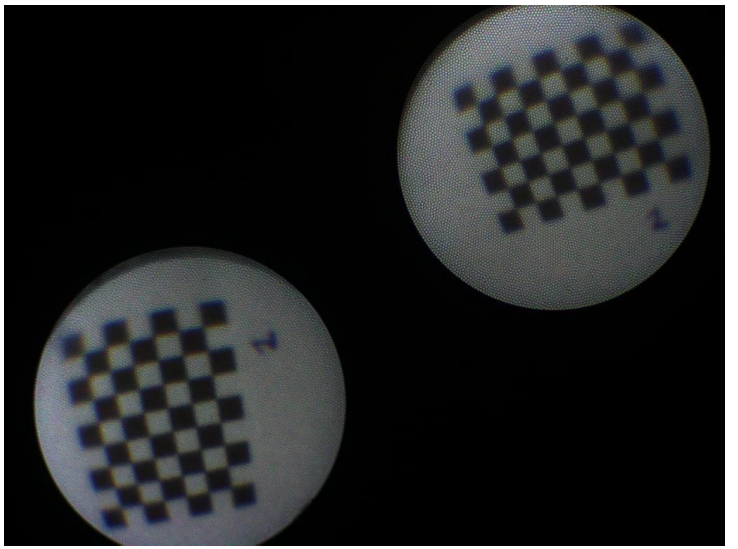
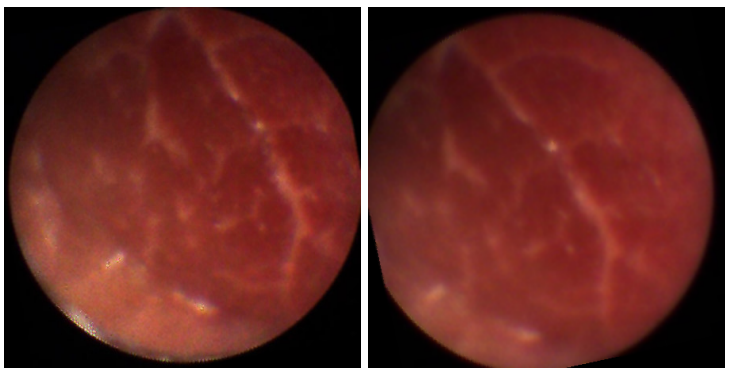
Calibration

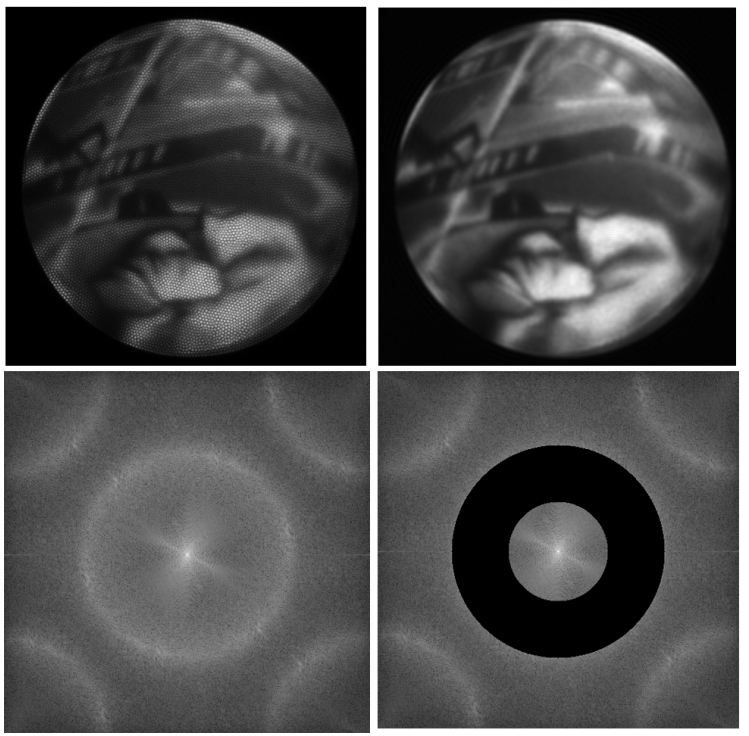
- Left camera image co-ordinate system defined manually
  - Due to arbiatry rotation of image around camera z-axis
- Right camera image co-aligned with that of the left image
- Stereo camera calibration performed
  - Camera intrinsic & extrinsic parameters
  - Manual corner detection due to poor image resolution
- Hand-Eye calibration
  - Rigid body origin to left camera centre





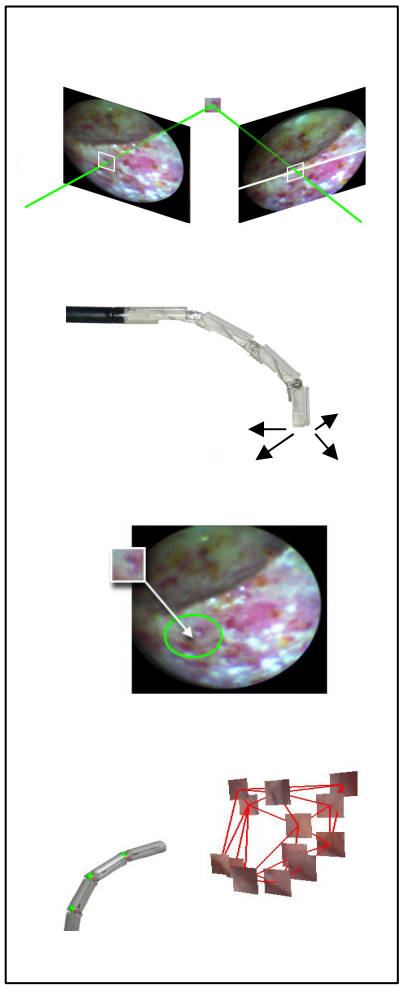
Preprocessing

- Honeycomb artifact removal
  - Honeycomb fibre structure visible
  - Bandpass filter in frequency space and Gaussian smoothing



SLAM Algorithm Design

- **Initialise: Feature detection**
- **Triangulate: 3D map feature**
- **Estimate Camera Motion**
- **Match Features: Active Search**
- **Update Camera and Map**



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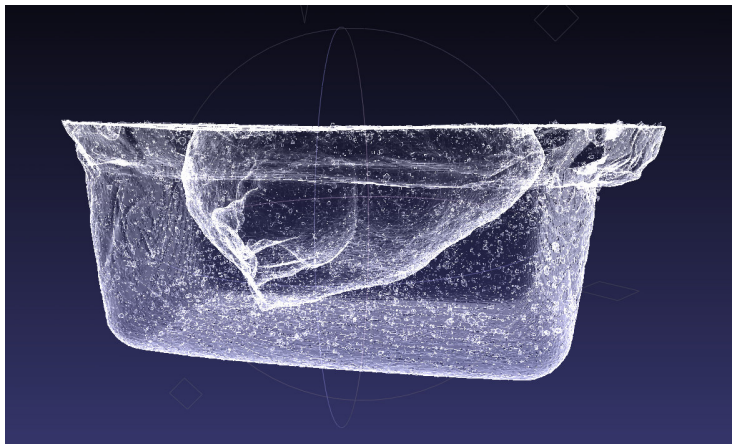
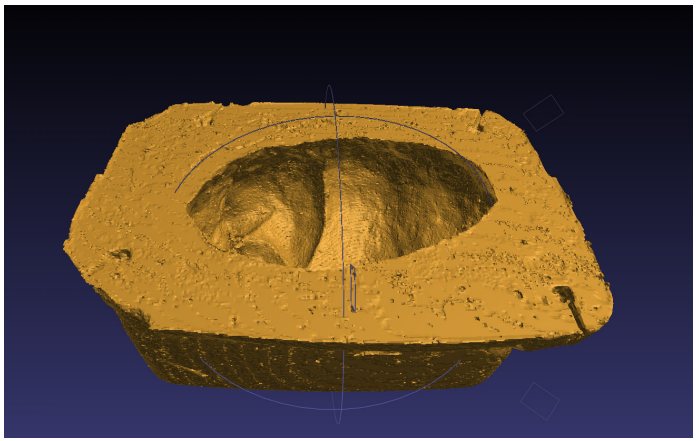
Validation Setup





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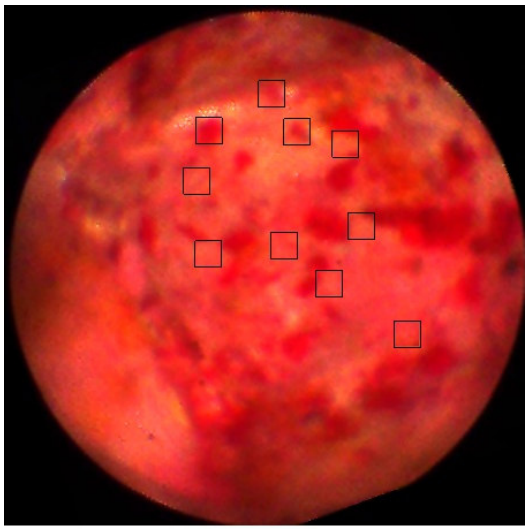
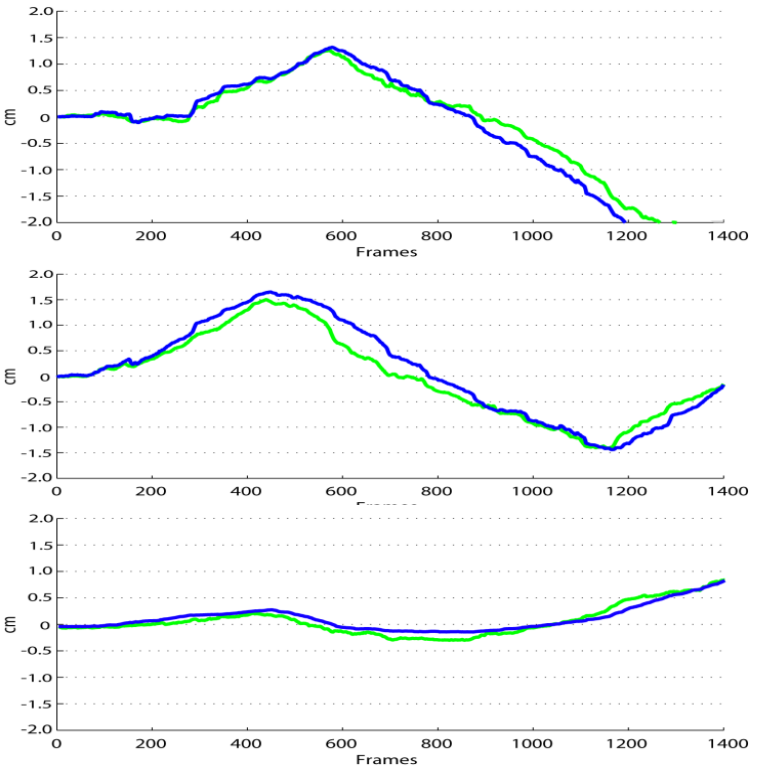
Results (1)

Camera Motion





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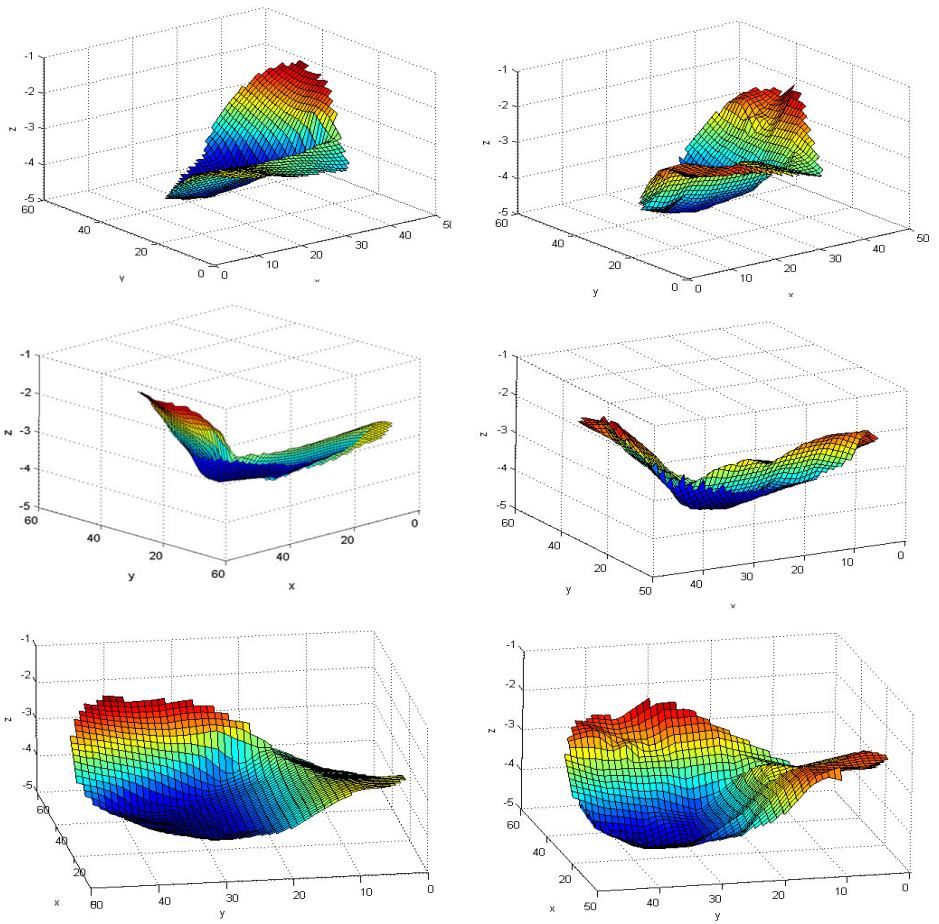
Results (3)

Surface Reconstruction

- Overall reconstruction error:
  - X – 2mm
  - Y – 1.3mm
  - Z – 2.9mm
- Z error larger due to small baseline



CT Ground Truth

SLAM reconstruction

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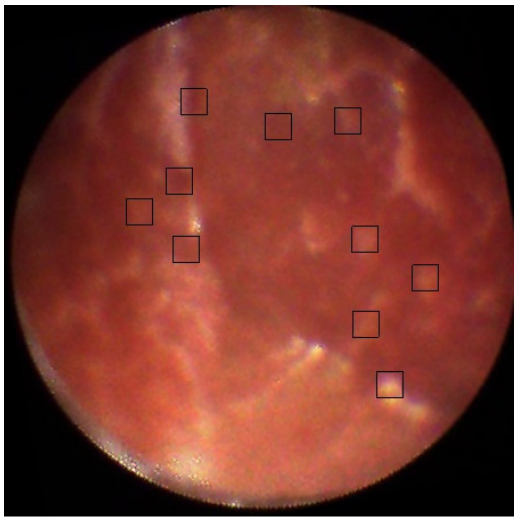
Results (2)

Camera Motion



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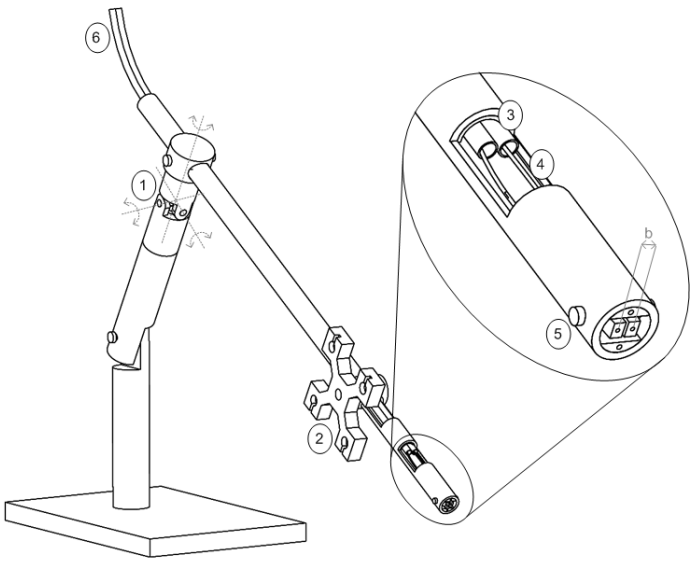
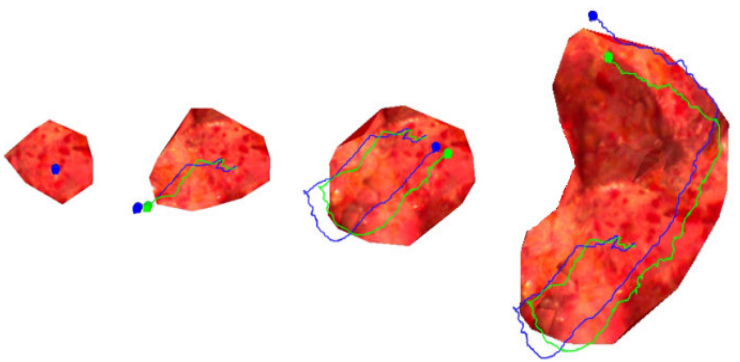
Conclusion

- Demonstrated feasibility of integrating twin flexible fibre guides in stereo configuration
- Described the challenges
- Successfully employed within a SLAM algorithm
  - Motion recovery
  - 3D Depth recovery
- Potential application
  - Within a catheter which utilizes the stereo vision for targeting and depth recovery for accurate focussed energy delivery





f = 50 *f* = 300 *f* = 700 *f* = 1400

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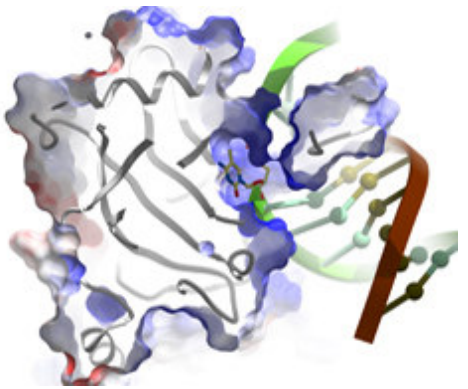
Acknowledgments

wellcome trust

EPSRC Engineering and Physical Sciences Research Council



The Hamlyn Centre for Robotic Surgery

Supported by Helen Hamlyn Trust

Technology Strategy Board

Driving Innovation

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Robotic Assisted Surgery

- Use of robotic surgery systems increases
- ≈ 900 units installed worldwide
- Majority of cases for radical prostatectomy
- Scope exists to enable ever more complex procedures