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Vision-Based Real-Time Surgical Instrument Tracking and Sample Mapping Device

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Motivation

We are developing a novel imaging device for intraoperative tissue classification using hyperspectral (HS) sensing. The preliminary results of our hyperspectral (HS) probe device on fresh *ex vivo* human cancer surgery specimens show promising diagnostic power.

By introducing tracking capability, we intend to develop a robust system for Intraoperative Margin Assessment (IMA) that can provide the surgeon an accurate visualisation of the tissue class map with augmented reality.

Background

Diffuse Reflectance Spctroscopy (DRS) setup:

- Diffuse Reflectance Spectroscopy (DRS) being low-cost, minimally invasive and non-ionising modality for quantitative Intraoperative Margin Analysis (IMA)
- The Ocean Optics Inc QR600-7-SR-125F reflection probe for DRS data acquisition, connected to spectrometer via optical fibre
- MATLAB for automated data acquisition and real-time spectra analysis

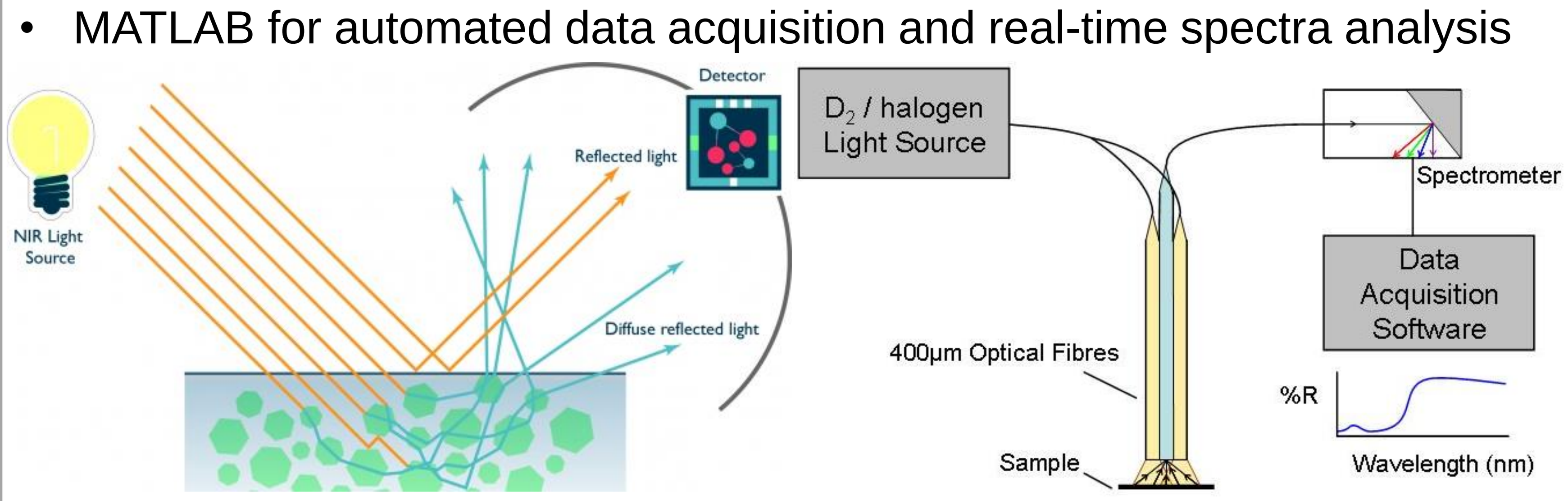
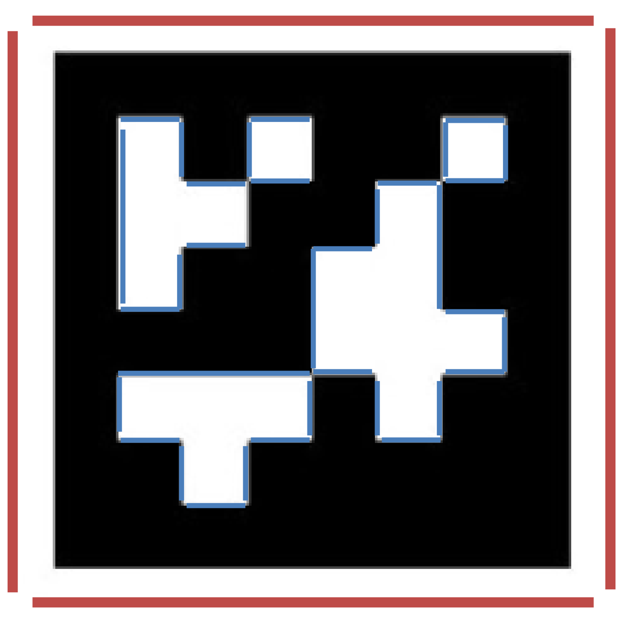


Fig. 1,2. Principles of DRS, Optical probe setup

QR Code Tracking Algorithm

1. Grab frame from camera.
2. Find the 2D vectors of every edge of the QR code at sub-pixel accuracy. *
3. Using the inner edges, find the QR code ID. *
4. Find 3D vectors of outer edges by triangulating the 2D vectors using a stereo-camera system.
5. Construct a plane using the 4 outer edge vectors, and find the orientation of the marker and the 3D-coordinate of the marker centre.

* From OpenCV ArUco Module [1]



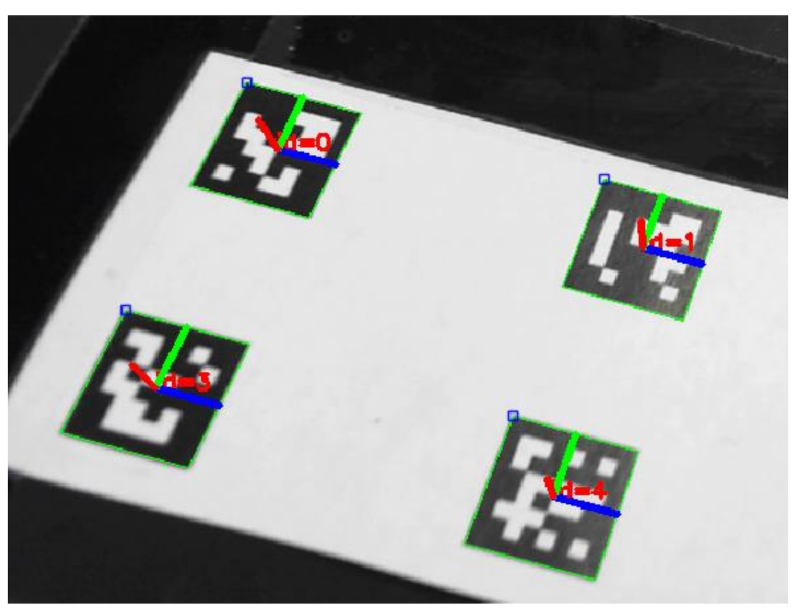


Fig. 3 (Left), Example of a QR code. Red lines = Outer edges, Blue lines = Inner edges.
Fig. 4 (Right), Visualised QR code tracking

Stereo-vision Setup

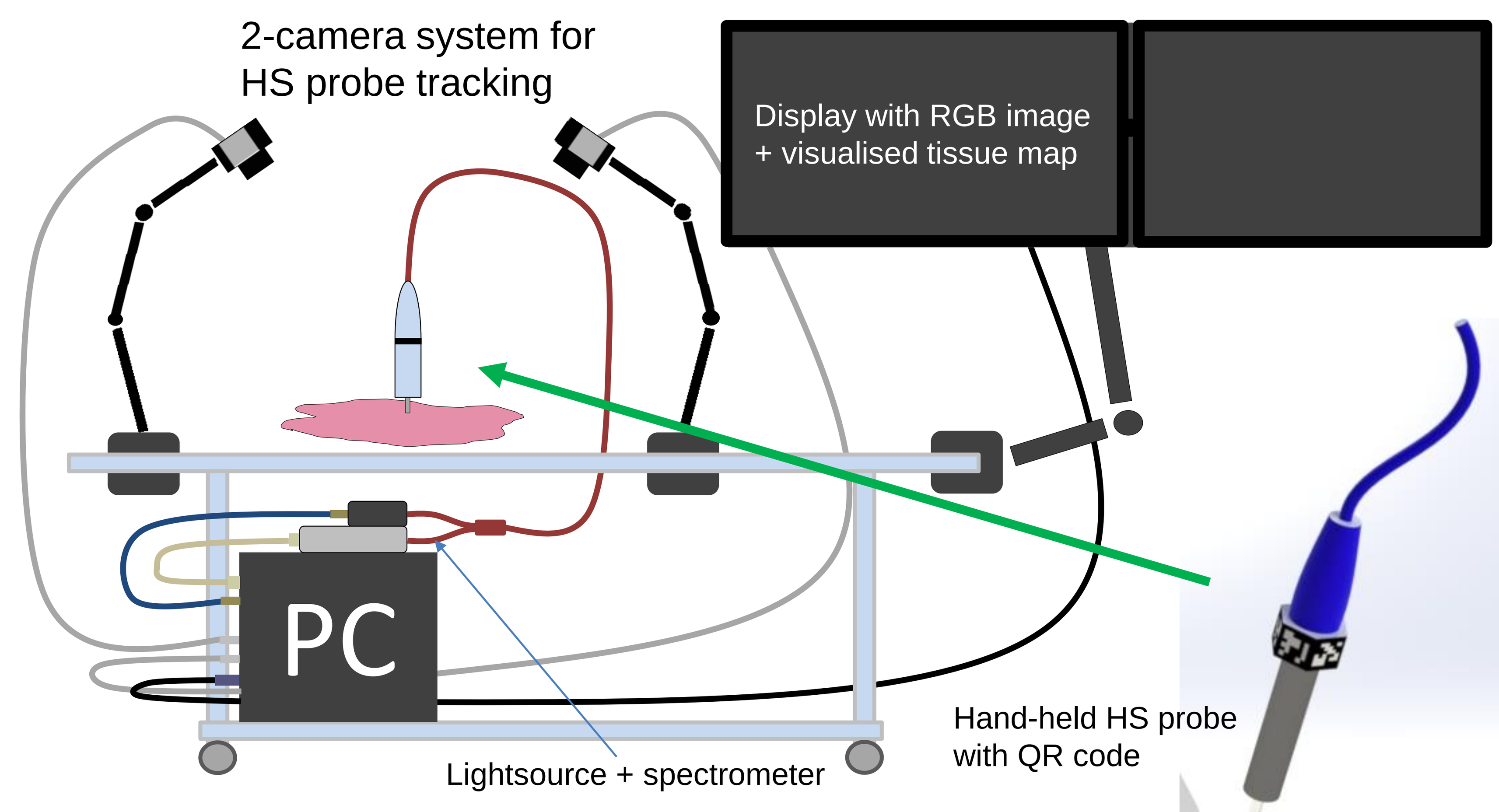


Fig. 5. Equipment setup, with emphasis to the probe

Optical Probe Tracking

- Consistent tracking on uneven surfaces using 2-camera system + 6 QR codes on hexagonal prism mount
- Noise minimisation using Median Absolute Deviation (MAD) filter + Hampel identifier.

Sub-degree and sub-millimetre accuracy could be achieved using 12.5 mm x 12.5 mm QR code, from 30cm working distance on 720p resolution (1280 x 720 pixels). Using this data, we can predict the probe-tip position accurately.

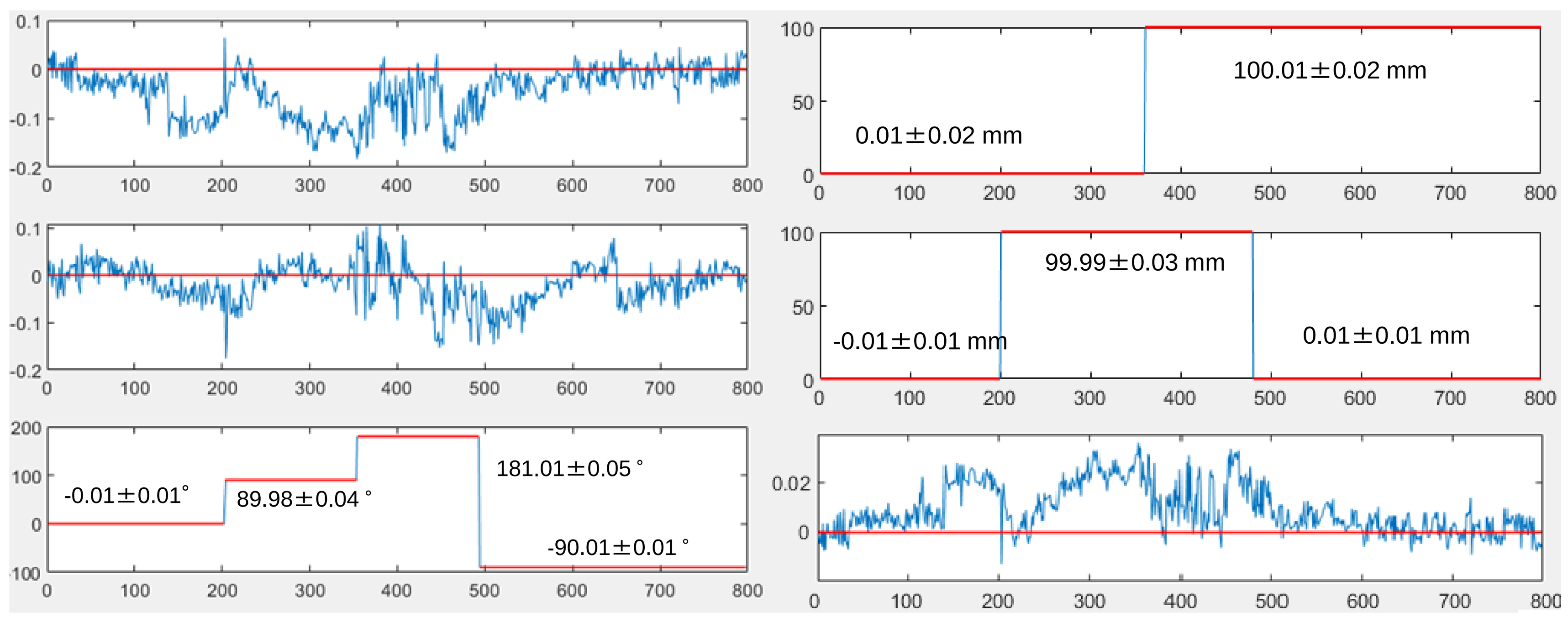


Fig. 6. Tracking performance (orientation in x,y,z (left), position in x,y,z (right), red line being ground-truth) at origin, 100mm(Y+), 100mm(X+), 100m (Y-), while rotating 90 ° every translation.

Frame transformation

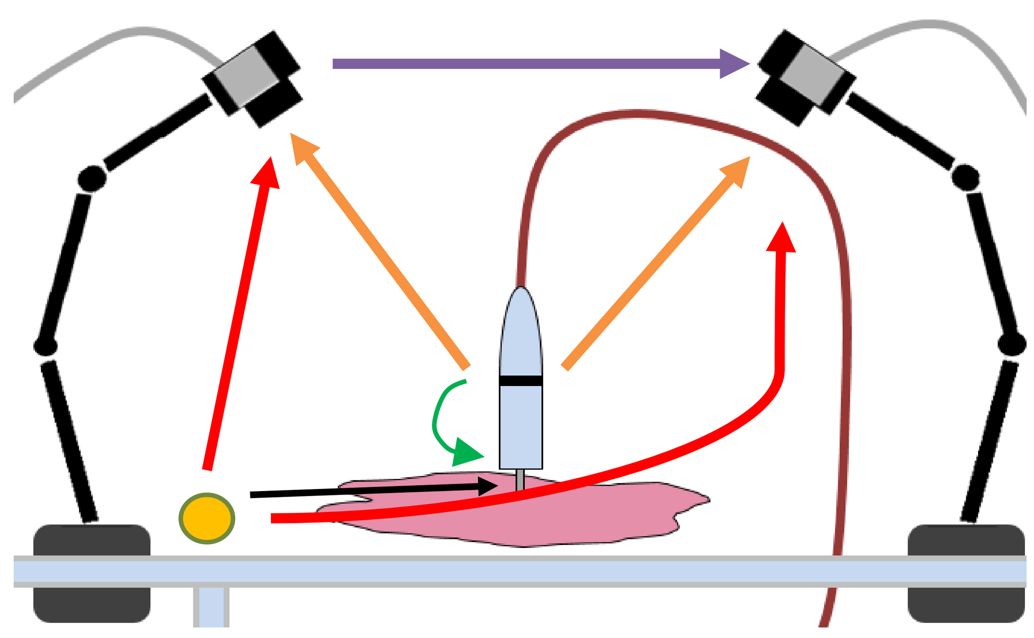


Fig. 7, Frame calculation plan (Yellow circle = Global Frame Origin)

- O, Orange arrows = QR code readings to each camera
- R, Green arrows = Pre-determined global axis to each camera
- P, Purple arrow = Location of 2nd camera relative to 1st camera, found by stereo-calibration.
- G, Green arrow = Pre-determined geometry of tool-tip relative to the marker position
- B, Black arrow (What we want) = Location of tool-tip relative to the global axis.

For left camera, $B = R_{left} * {O_{left}}^{-1} * G$

and for right camera, $B = R_{Left} * P * {O_{Right}}^{-1} * G \quad B = R_{Right} * {O_{Right}}^{-1} * G$

…where if $X = \begin{bmatrix} R & t \\ 0 & 1 \end{bmatrix}$, then $X^{-1} = \begin{bmatrix} R^T & -R^T * t \\ 0 & 1 \end{bmatrix}$

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References:
1. S. Garrido-Jurado, R. Muñoz-Salinas, F. J. Madrid-Cuevas, and M. J. Marín-Jiménez, "Automatic generation and detection of highly reliable fiducial markers under occlusion," *Pattern Recognit.*, vol. 47, no. 6, pp. 2280–2292, Jun. 2014

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