Laparoscopic Image Guidance via Conoscopic Holography

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Spatially registered 3D preoperative medical images can improve surgical accuracy and reduce reliance on memory and hand-eye coordination by the surgeon. They enable visualization of internal structures within the anatomy of a patient on the operating table. In the case of biopsy, for example, this would allow the surgeon to guide the needle tip to a tumor though opaque tissue. It has been well established that for soft tissues, image registration can be performed aligning the preoperative image with a cloud of points (Fig. 2) that describe the surface of an organ [1].

Collecting this point cloud can be challenging, generally requiring open surgery to permit line-of-sight access for laser triangulation (e.g. the system of Pathfinder Therapeutics, Inc.). We present a conoscopic holography-based system (Figure 1) for collecting a point cloud less invasively - through a laparoscopic port. The system consists of a commercial conoscope (Optimet, Inc., Probe Head Mk3), designed for precision machine-shop linear measurements, that is tracked (the surgical tool is also tracked) with an optical tracking system (Claron MicronTracker H3-60).

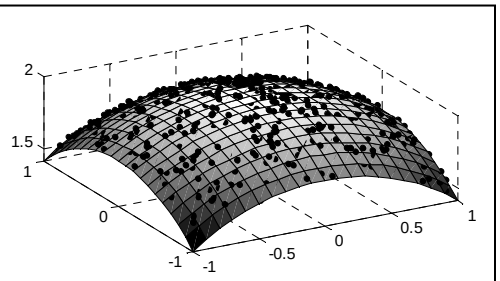

Figure 1. Conoscopic Holography scanning system. The tracked sensor returns distance measurements defining the shape of an organ in surface.

Figure 2. The conoscope returns a point cloud (black dots above) which can be used to align preoperative image information (surface) with intraoperative anatomy.

A potential source of error in collecting distance measurements with the conoscope is the diffusion and/or absorption of the red laser light by tissue. Thus, we conducted an experiment to establish the accuracy of the conoscope when measuring distances to biological tissues (see Figure 3). The accuracy observed in this experiment supports the hypothesis that conoscopic holography can facilitate image registration. Further experiments are currently underway assessing the accuracy of the complete system shown in Figure 1 in guiding a tracked needle to a desired subsurface target identified on preoperative images.

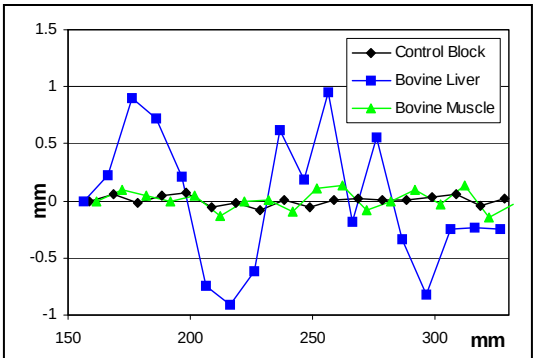

Figure 3. Experimental conoscope measurement error (vertical axis) vs. distance for biological tissues.

[1] Cash DM, Tuhin KS, Chapman WC, Terawaki H, Dawant BM, Galloway RL, Miga MI, 2003, "Incorporation of a laser range scanner into image-guided liver surgery: Surface acquisition, registration, and tracking", Medical Physics 30(7) pp.1671-1682

Conoscopic Holography for Image Registration

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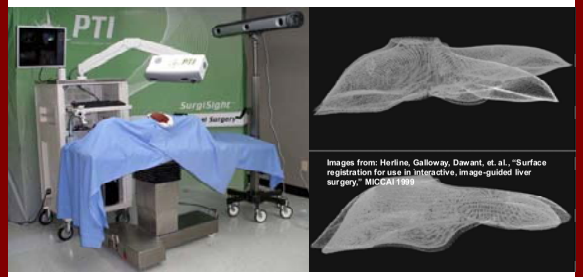
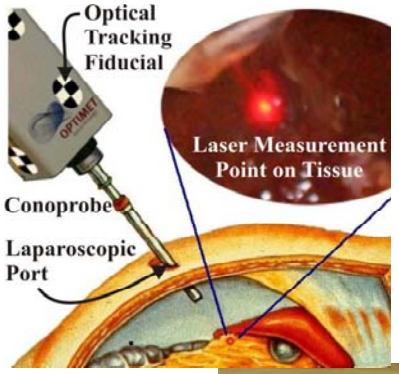
Introduction

- Spatially registered 3D preoperative medical images can improve surgical accuracy
- Soft tissue registration requires intraoperative surface contour sensing (obtaining a 3D point cloud)

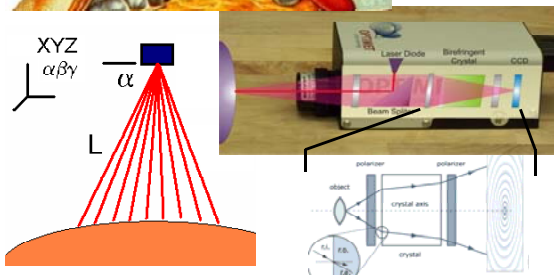


- The current commercial contour-based registration solution (Pathfinder Therapeutics, inc.) uses triangulation and thus requires open surgery.

Laparoscopic Contour Sensing

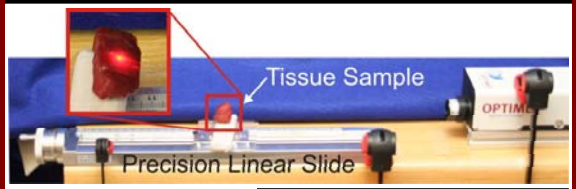


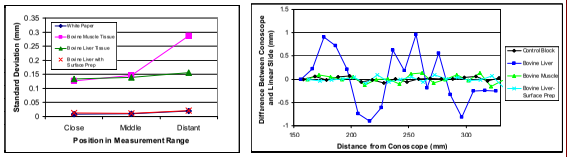
Proposed Laparoscopic Scanning System



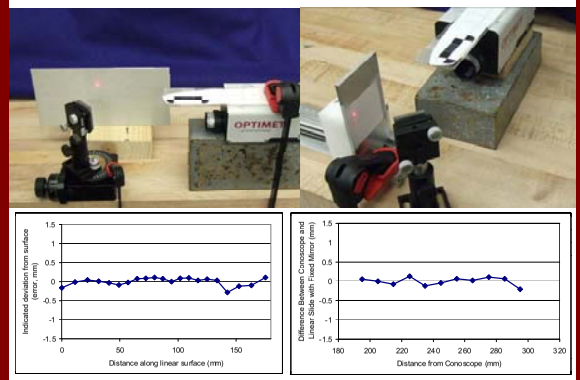
- Conoscopic Holography is a commercially available 1D absolute distance measurement system
- Conoscope measures distance to tissue surface
- Optical tracking of the conoscope can be use to convert distance measurement to a 3D point cloud.

1D Test Apparatus



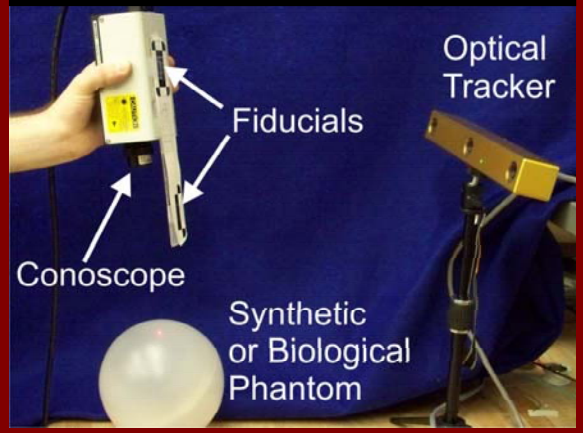


- Repeatability experiment for various tissue types



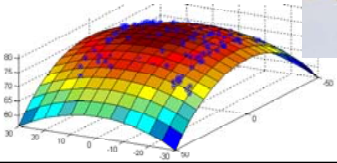
- Validation that distance measurements are accurate even when a mirror redirects the conosope laser

3D Test Apparatus



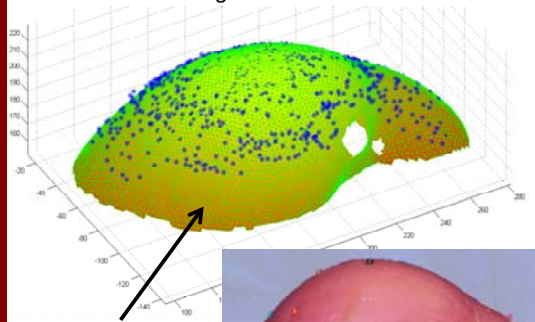
3D Results: Spherical Liver

- 80.4mm nominal radius (with ~5.4mm Liver Slice)
- 400 points collected
- Sphere fit to point cloud: radius = 81.0mm
- Std. dev. 0.61mm



3D Results: Liver Phantom

- Overlay of conoscope data registered to segmented CT scan data using ICP.



Segmented CT scan of liver phantom surface

Conclusions

- Experiments have demonstrated the feasibility of a Laparoscopic Conoscopic Holography-based 3D scanner for image registration
- Mirror experiments demonstrate the feasibility of an automated aiming mechanism at the tip of the laparoscope
- Novel application of industrial quality control technology to medicine.

References

- R. A, Lathrop and R. J. Webster III, "Conoscopic Holography for Image Registration: A Feasibility Study," Proceedings of SPIE, 2009.