Next-Generation Tracked Laparoscopic Ultrasound for Precision Surgery

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Objectives

- **Laparoscopic surgery** provides clear visualization of surface anatomy but **leaves critical subsurface structures hidden**, increasing the risk of bile-duct injury [1], incomplete tumor resection [2] or ablation [3], and other complications.
- **Laparoscopic ultrasound (LUS) offers real-time visualization** of vessels, ducts, and masses beneath the surface. However, its clinical adoption remains limited due to its **steep learning curve** and the challenge of spatially integrating ultrasound and laparoscopic images [4]. Navigation-enhanced LUS has shown promise for improving spatial awareness through **image fusion and augmented visualization** [5].
- We present a novel LUS probe that integrates two complementary tracking technologies – electromagnetic (EMT) and vision-based tracking – to **provide accurate, real-time localization of the probe tip within the surgical field**.
- Designed to work with Terason ultrasound systems, this probe aims to simplify LUS navigation, shorten the learning curve, and enable broader use of intraoperative ultrasound in laparoscopic surgery.

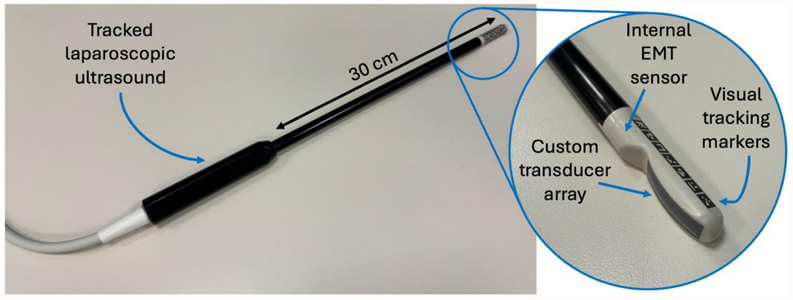

Figure 1: Laparoscopic ultrasound probe with dual electromagnetic and vision-based position tracking modalities built in.

Methods

- A side-viewing LUS probe was developed (Figure 1) with an **EMT sensor** embedded at the distal end and **laser-marked patterns** for optical probe detection in the laparoscopic camera view.
- EMT operates without line-of-sight but can be affected by metallic objects, whereas vision-based tracking is highly accurate but susceptible to occlusion by smoke or debris.
- The **dual-tracking approach combines the strengths of both methods to enhance reliability in surgical environments** [6].
- The integrated probe design supports one-time tracking calibration, avoiding per-use calibration required by previous systems [7].

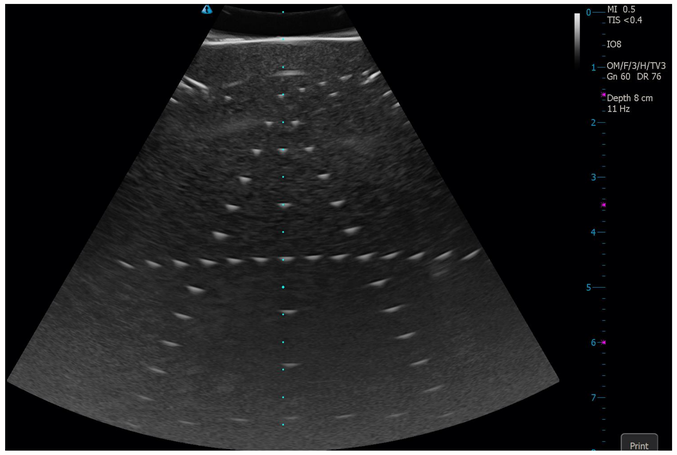

Figure 2: Ultrasound image of wire calibration phantom.

Results

- Preliminary **phantom studies demonstrated clear visualization** of point targets, with high contrast resolution and spatial accuracy at a depth of 6 cm, using a wire calibration phantom (Model 055A, CIRS Inc., VA, USA), as shown in Figure 2.

Results (cont.)

- EMT exhibited a mean error of 2.20 ± 1.23 mm and RMS precision of 0.16 mm, while vision-based tracking has previously been shown to improve tracking performance by 66% over EMT alone [6].

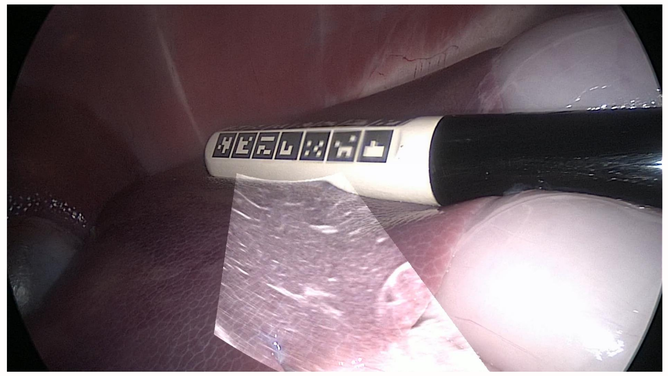

Figure 3: Demonstration of in-situ ultrasound image fusion with laparoscopic camera view.

Conclusion

- Tracked LUS probes can enhance laparoscopic procedures by providing ***in-situ* visualization of the ultrasound image** (Figure 3) and adding **real-time needle guidance** (Figure 4).
- By improving real-time localization and visualization of sub-surface anatomy, this technology has the **potential to increase procedural accuracy and reduce operative time.**

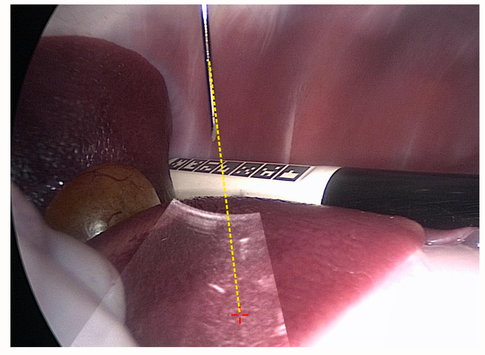

Figure 4: Enhanced needle guidance visualization using the proposed tracked laparoscopic ultrasound probe.

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Acknowledgements

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