Dense 3D Reconstruction Through Lidar: A New Perspective on Computer-Integrated Surgery

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Haptic Intelligence

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Introduction

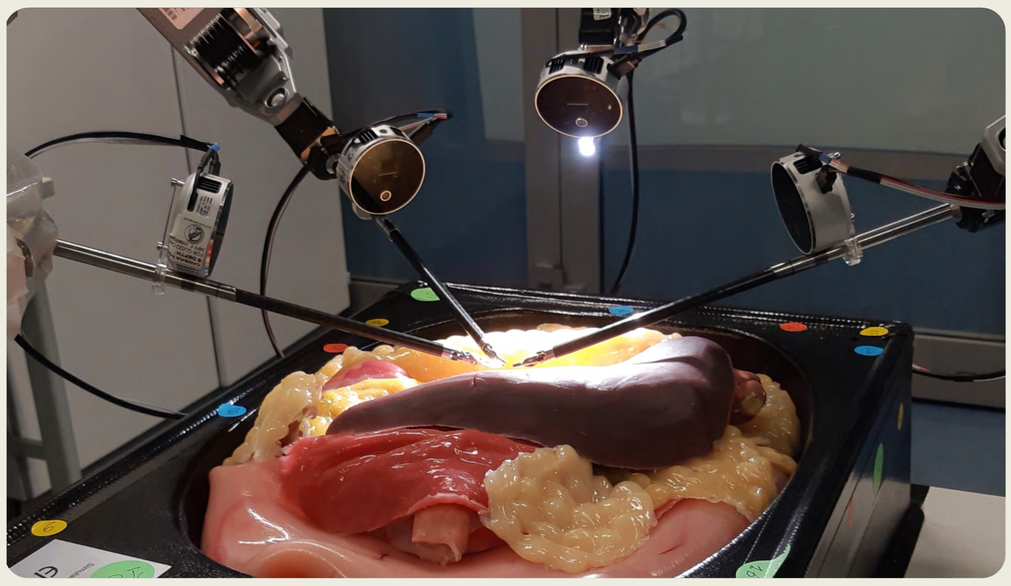
Context: technical innovations in sensing and computation are quickly advancing the field of computer-integrated surgery.

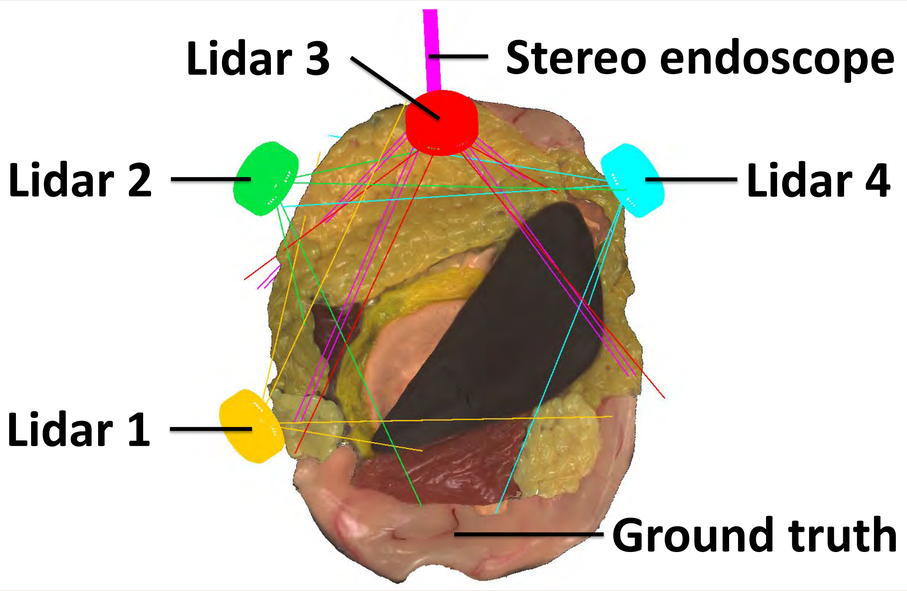
Problem: in this fast-evolving panorama, we strongly believe there is still a *need for robust geometric reconstruction* of the surgical field.

Limits to State of Art: 3D reconstruction in surgery has been investigated almost only in the space of monoscopic and stereoscopic visual imaging.

Parallel Technologies: *lidar* (light detection and ranging) has greatly expanded in use, especially in SLAM for robotics, terrestrial vehicles, and drones.

The concept of *multiple-viewpoint surgical imaging* was proposed in the early 2010's in the context of magnetic actuation and micro-invasive surgery.





Methods

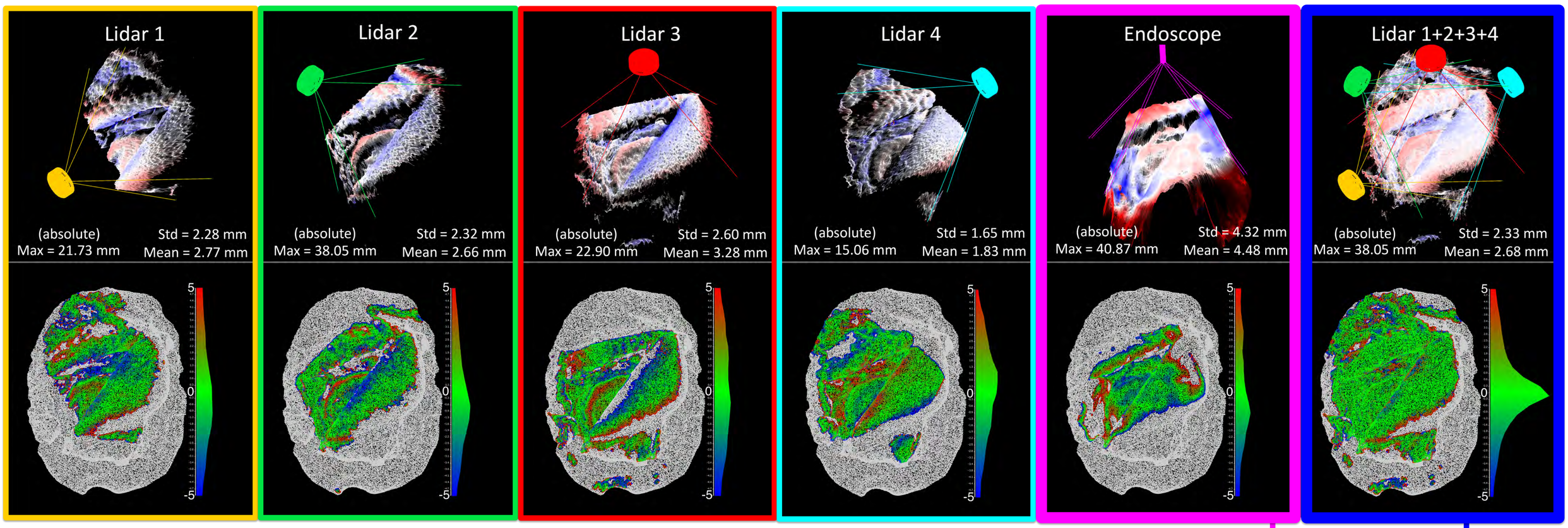
Idea: here we propose an approach in which *each surgical cannula can potentially hold a miniature lidar*.

Hardware Setup:

- da Vinci Si Surgical System
- Intel RealSense L515 lidar cameras
- Custom whole-abdomen phantom
- Artec Eva HD 3D scanner (ground truth)
- Raspberry Pi 4B (lidar external trigger)
- DeckLink Duo 2 (endoscope capture)

Software Setup:

- Ubuntu 20.04
- RealSense SDK & ROS wrappers (L515)
- DeckLink ROS drivers (custom)
- Artec Studio 16 (offline registration)
- CloudCompare (quantitative analysis)



Results and Conclusions

Quantitative Analysis

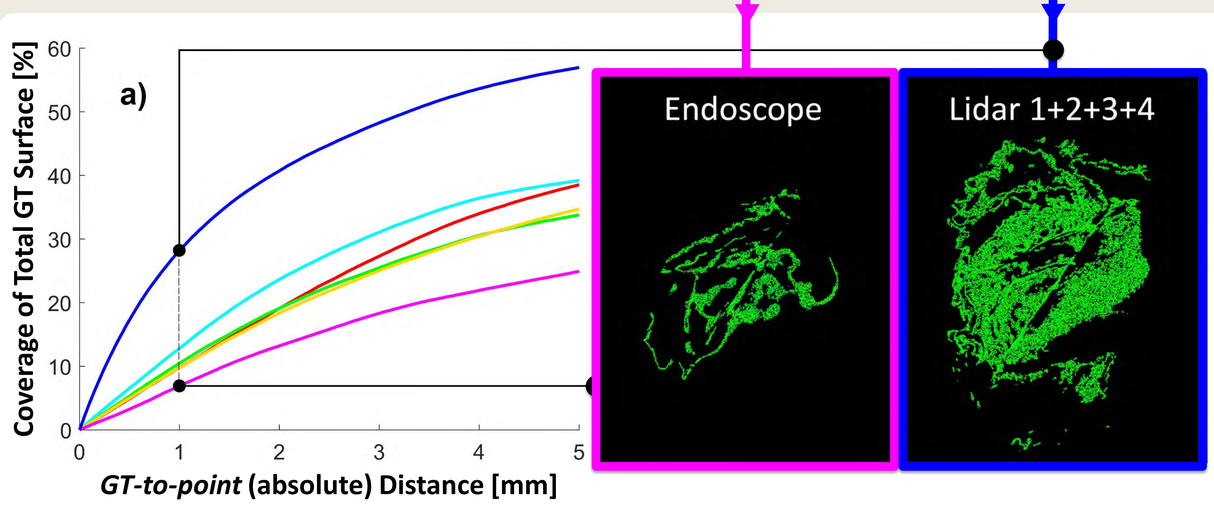
Accuracy Metric: *point-to-GT* scalar fields (blue-white-red mapping) are calculated for each point cloud as signed distance with respect to the ground truth.

Coverage Metric: *GT-to-point* scalar fields (blue-green-red mapping) show the ground truth surface covered in the distance range ±5 mm.

Comparison: Direct comparison between *lidar* from different viewpoints and a state-of-the-art 3D reconstruction method on stereoendoscope images showed *that lidar-generated point clouds achieve better accuracy and scene coverage*.

Performance: *each lidar* accurately (±1 mm) sees about 50% more of the ground truth surface than the endoscope. The *four lidars combined* accurately (±1 mm) reconstruct about 30% of the total ground truth surface.

***Lidar* is a promising technology for computer-integrated surgery.**



Future work

- Cloud-to-cloud online **automatic registration** (in real time)
- Test in a **dynamic environment** (e.g. presence of surgical instruments, moving cameras, surgical interactions)
- Real-time **3D visualization** (e.g. surgeon console, holographic viewer)
- **Miniaturized** surgery-compatible lidar sensor

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