Software for an Intra-Operative Kinect with a Flexible Endoscope

Seminar Presentation

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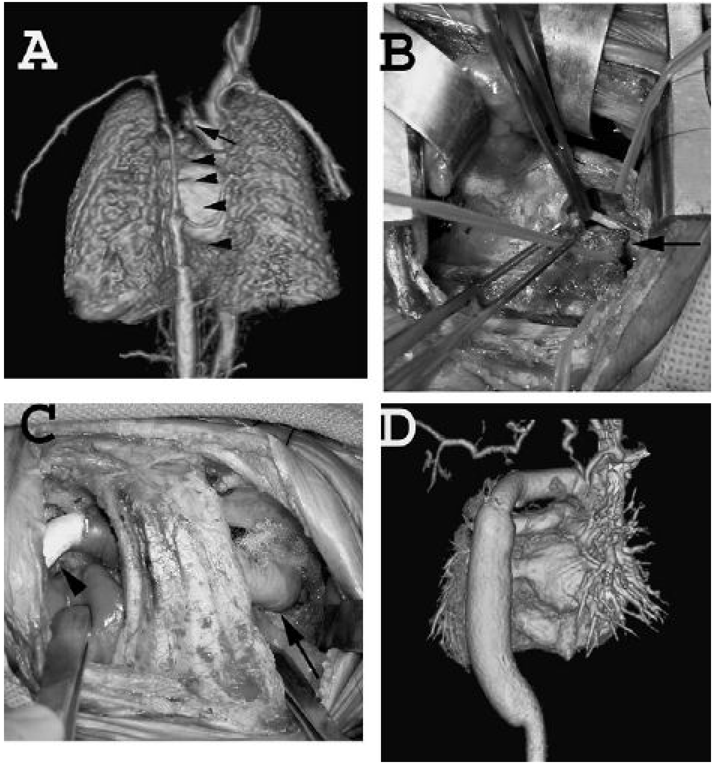
Background

- Small laser fiber inserted down the working channel of a flexible endoscope
- Structured light reconstruction of a small intra-operative space
- Needs to work accurately and in real time

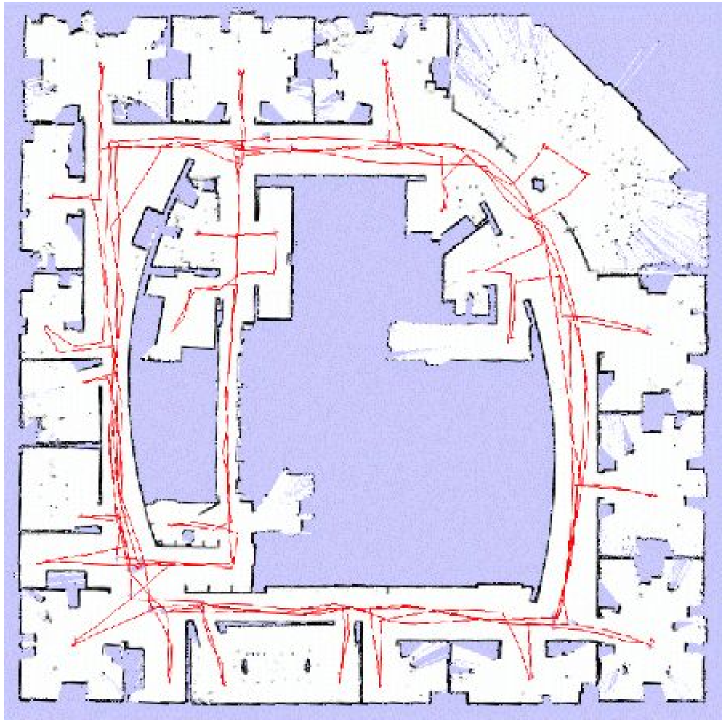


https://www.researchgate.net/profile/Omar_Tamimi/publication/5590658/figure/fig1/AS:277891112816692@1443265812740/Fig-1-A-Preoperative-CT-angiography-3D-reconstruction-showing-absent-distal-aortic.png

Simultaneous Localization and Mapping (SLAM)

Goals:

1. Incrementally construct a map of an unknown 3D environment
2. Identify and keep track of the location of a vehicle or tracker within this environment



http://www.cc.gatech.edu/~kaess/images/intel_map.gif

Literature Review

Gamini Dissanayake, M.W.M., Newman, P., Clark, S., Durrant-Whyte, H.F., and Csorba, M. "A Solution to the Simultaneous Localization and Map Building (SLAM) Problem." ***IEEE Transactions on Robotics and Automation*** **17.3. (2001): 229-241. Print.**

Moutney, P., Stoyanov, D., Davison, A., and Yang, G.Z. "Simultaneous Stereoscope Localization and Soft-Tissue Mapping for Minimal Invasive Surgery." *Medical Image Computing and Computer-Assisted Intervention* 4190. (2006): 347-354. Print.

A Solution to the SLAM Problem

Given:

1. Vehicle with a known kinematic model
2. Linear, discrete-time model of evolution of vehicle and observation of landmarks
3. Landmarks are assumed stationary

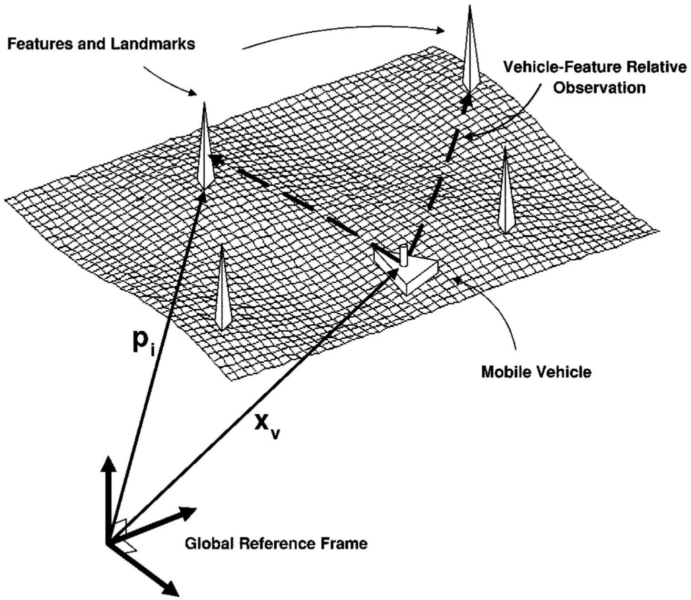


Fig 1. A vehicle taking relative measurements to environmental landmarks.

A Solution to the SLAM Problem

Mathematical conclusions:

1. Uncertainty in the relative map estimates reduces monotonically.
2. In the limit, uncertainty in the map estimates converges to zero.
3. Uncertainty in the vehicle and absolute map locations achieves a lower bound determined by the error in the initial vehicle location estimate.

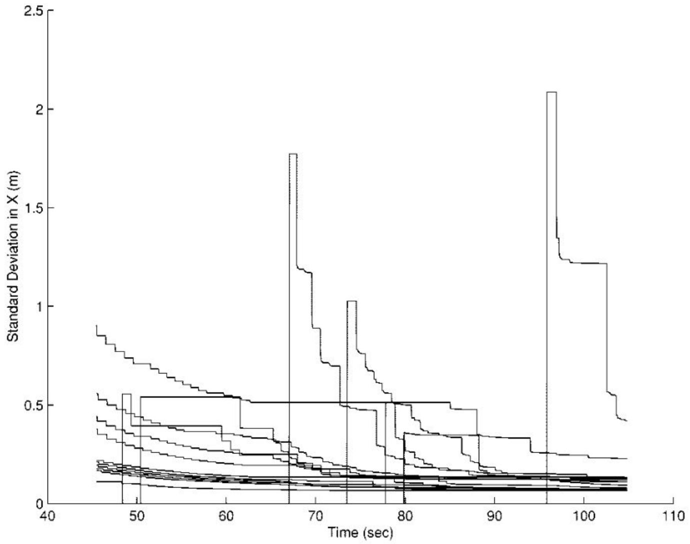


Fig 12. Decreasing uncertainty in location landmark estimates.

A Solution to the SLAM Problem

Experimental conclusions:

- Standard road vehicle equipped with millimeter wave radar (MMWR)
- Landmarks: radar reflectors and natural structures

Results:

- Actual vehicle error is bounded by confidence limits of estimated vehicle error
- Absolute error: 5 cm

Fig 2. The test vehicle, showing mounting of the MMWR and GPS systems.

A Solution to the SLAM Problem

Limitations:

- Need to maintain a full state vector of all states of both the vehicle model and every landmark in the map
- Effectiveness of algorithm depends on operating environment (e.g. if geometric features can be detected)
- Need a way to validate accuracy of algorithm

https://upload.wikimedia.org/wikipedia/commons/8/83/Underground_mine_Ales_1.jpg

Literature

Gamini Dissanayake, M.W.M., Newman, P., Clark, S., Durrant-Whyte, H.F., and Csorba, M. “A Solution to the Simultaneous Localization and Map Building (SLAM) Problem.” *IEEE Transactions on Robotics and Automation* 17.3. (2001): 229-241. Print.

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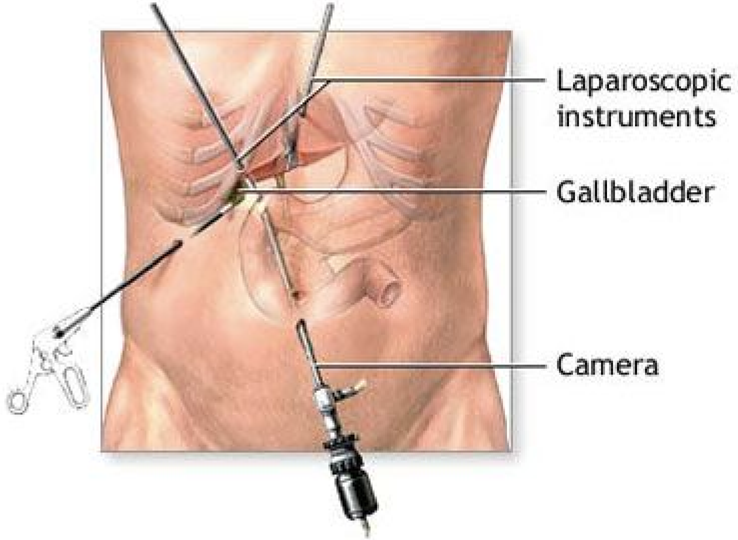
SLAM Mapping in MIS

Limitations of MIS:

- Narrow range of motion and camera field of view
- Loss of 3D vision and perception
- Navigation and localization can be difficult
- Variable lighting conditions
- Curved environment makes feature extraction challenging



http://www.drleongmd.com/wp-content/uploads/2012/03/Minimally-Invasive-Surgery.jpg

SLAM Mapping in MIS

Experimental procedure:

1. Stereoscopic laparoscope pre-calibrated before procedure
2. Camera motion controlled so that inter-frame motion is < 20 pixels
3. Realistic image rendition projected onto plane
4. Features thresholded and matched using normalized SSD and epipolar geometry

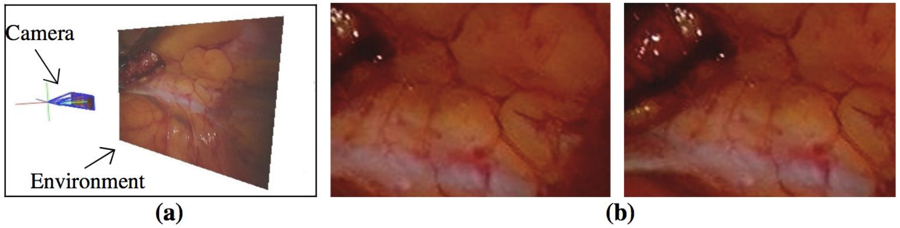


Fig. 3. An illustration of the simulation environment used to generate a stereo-laparoscopic video with known ground truth data for camera motion. A 3D rendition of the virtual world is shown in (a) and an example stereo pair taken from the virtual cameras is shown in (b).

SLAM Mapping in MIS

Prediction step:

- Statistical motion model
- Takes into account unknown intentions of the camera operator
- Deterministic: on average, “constant velocity, constant angular velocity”
- Stochastic: on average, small changes in acceleration

	Advantages	Disadvantages
Small Pn	smooth motion small accelerations	cannot cope with sudden rapid changes
High Pn	can cope with rapid accelerations	a lot of good measurements must be made at each time step to constrain estimates

SLAM Mapping in MIS

Measurement step:

- New input can reduce uncertainty in position measurements
- Can use SLAM to calculate predicted position of feature in world coordinates
- Search around this predicted position to find actual feature
- Compare SLAM map with actual visual input

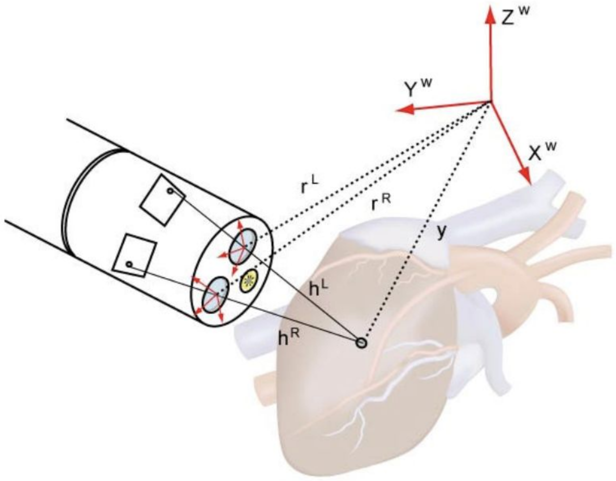


Fig. 1. Stereo-laparoscope camera geometry. The figure illustrates the geometry between a global coordinate system, the local camera coordinates and a selected point from the map.

SLAM Mapping in MIS

Results:

- Uncertainty in measurements reduces as stereoscope moves
- Robust to changes in direction and lighting
- When used on reversed video footage, tracking is able to follow the camera back to its original position

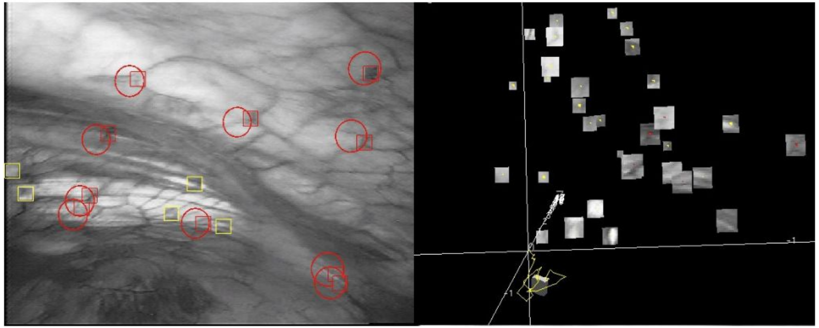
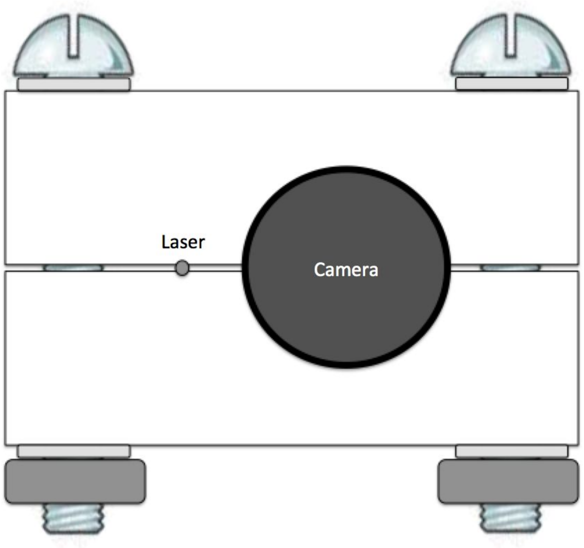


Fig. 7. Typical features selected in the left stereo image plane and the corresponding landmarks projected onto 3D coordinate system by using information built into the SLAM map.

Conclusions

- SLAM can produce effective 3D reconstruction and vehicle tracking in complex environments
- Dependent on reliable detection of features under varying spatial and lighting conditions



References

1. Gamini Dissanayake, M.W.M., Newman, P., Clark, S., Durrant-Whyte, H.F., and Csorba, M. “A Solution to the Simultaneous Localization and Map Building (SLAM) Problem.” *IEEE Transactions on Robotics and Automation* 17.3. (2001): 229-241. Print.
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Questions?