Software for an Intra-Operative “Kinect” with a Flexible Endoscope

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Relevance:

With the commercial release of “depth cameras” such as the Microsoft Kinect in recent years, 3D reconstruction has become a much more approachable and popular research topic in computer vision. Such cameras operate by projecting a grid or pattern of light points onto a scene, and are able to determine the relative depth and location of nearby objects in real time. This is particularly of interest in fields such as medicine, where the ability to dynamically reconstruct an environment in the body in real time can assist physicians with selecting treatments and assist surgeons during complex operations.

One common technique to look inside the body is an endoscopy, a procedure in which a small camera attached to a flexible wire or tubing is inserted into a hollow organ or cavity. Endoscopies may be used to look for abnormalities such as deformations, foreign objects, or excess fluid, and could be greatly assisted by a 3D representation of the space being viewed by the camera.

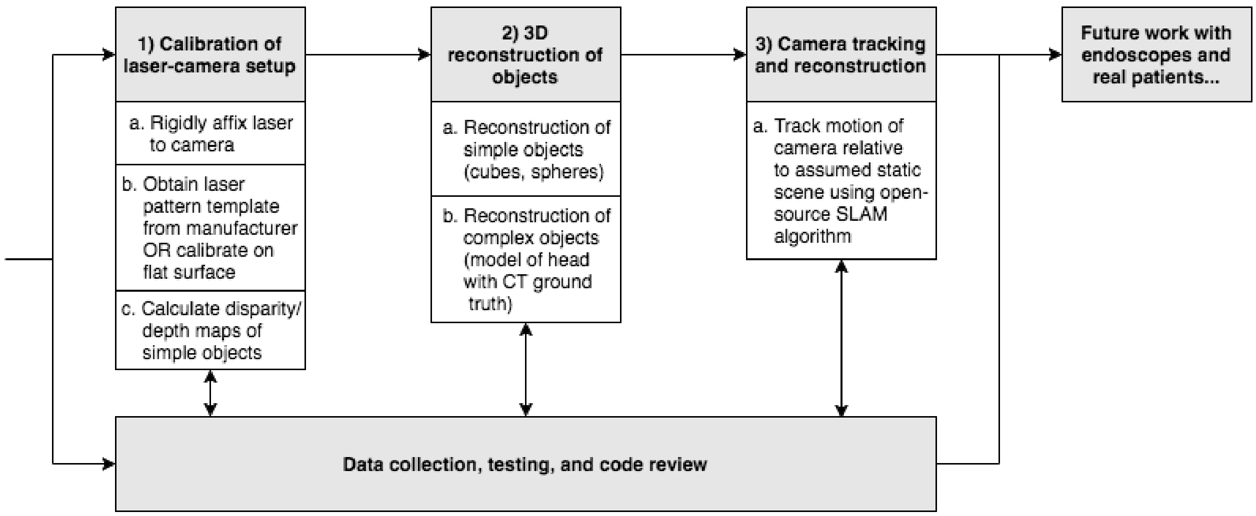
This technology would be particularly useful in sleep apnea patients, where collapse of structures in the throat can lead to obstruction of the airway. Understanding the details of each patient’s anatomy is critical for guiding surgical decisions, so a 3D reconstruction of the patient’s airway during an endoscopy would inform the surgeon’s decision-making process. For this reason, we hope to show that we can accurately perform a 3D reconstruction using a small laser connected to a small camera, and that such a setup can be incredibly valuable and reliable for real time reconstruction in an intraoperative space.

Technical Approach:

Our first step for this project will be calibration of the laser-camera setup. The laser’s pattern must be determined, either by obtaining a template from the manufacturers or by measuring it from a projection onto a flat surface normal to the camera’s optical axis. To ensure this process does not need to be performed every time the device is used, we will need a secure method to fixate the laser to the camera that will last for the duration of the semester. Next, we will write calibration code to calculate a disparity map based on images of static objects. This will initially be performed with basic objects such as cubes and spheres to make sure that the algorithm works, and then we will proceed to more complex objects for which exact dimensions are known. This disparity map can then be converted to a depth map using properties of the setup like the camera’s focal length and the baseline distance between the laser and the camera. We will need to test this calibration by testing our code with images of simple objects at a known position relative to the camera.

Once the calibration code is within at least a millimeter of accuracy, we will use this depth map to compute a 3D reconstruction of the objects in the field of view of the camera. We will first write code to compute this reconstruction, then test our code with a variety of objects. We’ll begin with simple objects such as a sphere with known diameter, and progress to more complex objects for which we have 3D models to allow for quantitative evaluation of the accuracy of our reconstruction. For example, we'll use a plastic model of a head with known CT to use as the ground truth for comparison. Once again, our goal will be to get within a millimeter of accuracy.

Finally, we will work on developing code for camera tracking by adapting an open-source package for simultaneous localization and mapping (SLAM) such as BreezySLAM, to track the motion of the camera relative to the (assumed) static scene.



Deliverables:

Our minimum deliverables include:

- Rigid fixation method of camera to laser (2/25/17)
- Template for laser pattern in appropriate coordinates relative to camera (3/4/17)
- Code to compute depth map based on camera's field of view (3/25/17)
    - Assess accuracy using setup with objects at known positions relative to camera, need at least millimeter accuracy
- Code to create 3D reconstruction of simple objects based on depth map (4/8/17)
    - Assess accuracy using simple objects with precisely known 3D shapes, need at least millimeter accuracy

Our expected deliverables include:

- Code to create 3D reconstruction of complex objects based on depth map (4/15/17)
    - Assess accuracy using complex objects with precisely known 3D shapes, need at least millimeter accuracy

Our maximum deliverables include:

- Code to track camera movement relative to static scene to stitch together static 3D reconstructions (5/13/17)
    - Assess accuracy using camera movement with static scene and quantification of error in computed camera movement relative to ground truth, need at least millimeter accuracy

Key Dates & Assigned Responsibilities:
Elli will focus on the setup of the laser-camera system and writing scripts to test the accuracy of our code, while Shohini will focus on writing the code to compute depth maps and 3D reconstructions. All data collection and code review will be done together.

The following are items we will be working on this semester during the weeks ending on the dates given:
2/25/17 - work on rigid fixation of camera to laser, begin development of calibration code
3/4/17 - collect data for baseline laser pattern, continue development of calibration code
3/11/17 - finalize code for calibration, plan testing setup and write testing scripts for calibration
3/18/17 - collect data, test accuracy of calibration, update calibration code appropriately
3/25 - Spring Break
4/1/17 - begin 3D reconstruction code, plan testing setup for 3D reconstruction
4/8/17 - test 3D reconstruction code on simple objects, refine code, collect data from simple objects
4/15/17 - test 3D reconstruction code on complex objects, refine code, collect data from complex objects
4/22/17 - begin camera tracking code, plan testing setup for camera tracking
4/29/17 - continue developing camera tracking code, continue planning testing setup for camera tracking
5/6/17 - collect data for testing camera tracking code
5/13/17 - test camera tracking code, update camera tracking code

Dependencies:

Dependency	Plan for Resolving
Access to laser & camera	Resolved on 2/10
Access to lab space for storage/testing	Resolved on 2/17
Reliable fixation for camera and laser	Work with Tae Soo Kim on 2/23
Development of testing setup	Work with Tae Soo Kim
3D Reconstruction depends on calibration	Seek guidance from Dr. Reiter if problems arise
Camera tracking depends on 3D reconstruction	Seek guidance from Dr. Reiter if problems arise
Obtaining Tae Soo Kim's prior work	Reach out to Tae Soo Kim and Dr. Reiter to obtain
Obtaining calibration code	Dr. Reiter will reach out, otherwise we will develop code

Management Plan:

We will have weekly meetings with Dr. Reiter to give progress updates and receive any needed guidance on our next steps or obstacles we encounter. In addition, we'll have periodic meetings with Dr. Taylor for progress updates and guidance.

Reading List:

1. Neibner, Matthias et al. (2013). Real-time 3D Reconstruction at Scale using Voxel Hashing. Retrieved from http://www.graphics.stanford.edu/~niessner/papers/2013/4hashing/niessner2013hashing.pdf
2. Real-time 3D Reconstruction at Scale using Voxel Hashing (YouTube). https://www.youtube.com/watch?v=XD_UnuWSaoU
3. Al-Naji, A. et al. (2017). Real Time Apnoea Monitoring of Children Using the Microsoft Kinect Sensor: A Pilot Study. https://www.ncbi.nlm.nih.gov/pubmed/28165382
4. Filko, Damir et al. (2016). Wound detection and reconstruction using RGB-D camera. http://ieeexplore.ieee.org/document/7522325/?reload=true&section=abstract
5. Khongma, A. et al. (2014). Kinect Quality Enhancement for Triangular Mesh Reconstruction with a Medical Image Application. http://www.springer.com/cda/content/document/cda_downloaddocument/9783319046921-c2.pdf?SGWID=0-0-45-1445170-p176547379
6. Tae Soo Kim's reports from CIS 2 project (and maybe code and MS thesis)
7. Patent application by Tae Soo Kim and Drs. Taylor and Reiter: http://www.freepatentsonline.com/y2016/0143509.html
8. SLAM algorithm: https://github.com/simondlevy/BreezySLAM