Mixed Reality Surgical Team Training: Created an Endoscope surgery simulator: Final Report

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Abstract:

We propose a solution to provide an endoscopic surgery training simulator for training rookie surgeons and solve the problem of limited training sources.

The simulator will locate the endoscopic tools via stereo camera and render the model of tools on the screen. The tools are overlaid on the virtual simulation environment to create a training setup. The whole system behaves just like "Augment Reality", but the output is on a 2D screen just like the regular endoscopic surgery.

The simulator can locate the tools at millimeter level accuracy and can maintain the performance of at least 30FPS constantly within a normal computer.

Need to mention that this is a status report. The demo for the system is created and all the objects are finished or partially finished. Further development and future human experiment are expected but the actual performance of the simulator in terms of training humans is unknown at this stage.

Introduction

Laparoscopic surgery has many advantages over traditional open surgery. Compared to traditional surgery, laparoscopic surgery has a much smaller abdominal incision, reduced trauma, and prevents undue loss [5]. During laparoscopic surgery, an endoscope was inserted through a keyhole on the patient's abdominal wall. The real-time image captured by the endoscope is displayed on a monitor, and based on the visual guidance, the surgeon manipulates laparoscopic instruments to perform the procedure.

Laparoscopic surgery is the preferred approach for various procedures, but it comes with the ergonomics and perception of the surgeon due to: (i) the fulcrum effect, (ii) the mislocation and misorientation of the endoscope display [3], and (iii) poor depth visualization [2].

Due to the difficulty, it required lots of training from a trainee to a qualified surgeon, and the time cost and economic cost are not small either. The traditional method for training novice surgeons is using box simulator, recently several Augmented Reality based surgical simulator has been developed [1][7][8][9] and several studies proved the effectiveness of using virtual reality or augmented reality technic to train the surgeon [6], but most of them only considered several specific types of procedure and ignore the robot-assist surgery system integration.

We use the Augments reality technic to create a simulation environment to train the surgeon. The simulator will locate the position and pose of the tools and will overlay tools on the virtual anatomy structure. Like the Da Vinci simulator for traditional endoscopic surgery but with minimal hardware involved to keep the system accessible and easy to use.

Furthermore, Da Vinci also required some assistants to hold tools near the bed, and their technic is like regular endoscopic surgery, thus the system can be combined with Da Vinci System to use the existed anatomy simulator for bedside assistant training. And can be integrated with the Da Vinci System build-in simulator to train the whole team together.

Technical Approach

The most important part of the entire system is correctly locating the position and pose of the endoscopic tools. The team decided to use a stereo camera as the main detector method for the following reason: 1. High accuracy. 2. Compatible with hand-held tools. 3. Can combine with current machine learning trends for future development.

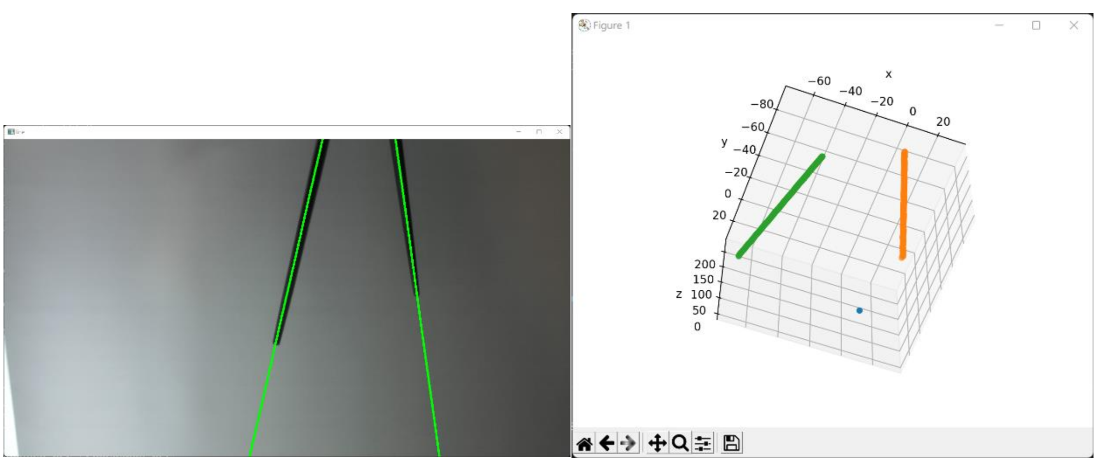
Hardware setup: A stereo camera was put in the main entrance of the anatomy phantom and facing inside the phantom. 2 LED stripes were attached to the phantom to provide better illumination. All the unused opening was covered to minimize the noise influence. Please refer to graph 1 and graph 2 for the setup of the system.

Graph 1: Main Setup

Graph 2: Inside Phantom view

Initially, the team wants to obtain the point cloud of tools, but due to the limitation of computing power, and the deficient performance of feature matching algorism on endoscopic tools, the team decided to combine with the geometry constrain to detect the centerline of endoscopic tools.

Graph 3 and Graph 4: Detecting Raw data point



Graph 5 and Graph 6: Filter feature points and calculate 3d coordinate

The pipeline shows in graph 3-6. Pipeline includes three stages. 1. Detect raw feature points. 2. Filter the feature points using geometry constrain 3. Obtain the space coordinate of feature point using triangulation method and calculate the 3d space straight line equation. Will discuss

1. Detect raw feature points.

The system will simply use the binary method to detect the dark area of the image. Most of the endoscopic tools that were used on Da Vinci are black so the image can simply detect the area where tools belong. Tools that were made of metal and looked silver can also be detected because of the high contrast between the background and tools. Then the system will calculate the center pixel of the gray area as a raw feature point. The “center pixel” refers to the center pixel of a dark area in a horizontal direction.

2. Filter the feature points using geometry constrain

Since most of the tools are long, uniform cylinder shape objects, their calculated raw feature point on the image should be straight and correctly reflect the actual centerline of the tools. The straight-line detection algorism was used to initially filter out the noise that came from the dark area of the image. Most of the dark areas will form an irregular centerline so Hough transform can simply filter out them. Need to mention that because of the problem of Hough detecting tilt lines, all the raw feature points were bold in the horizontal direction for 2 pixels for robustness. Bold the point only applied at this stage and will not carry on forward.

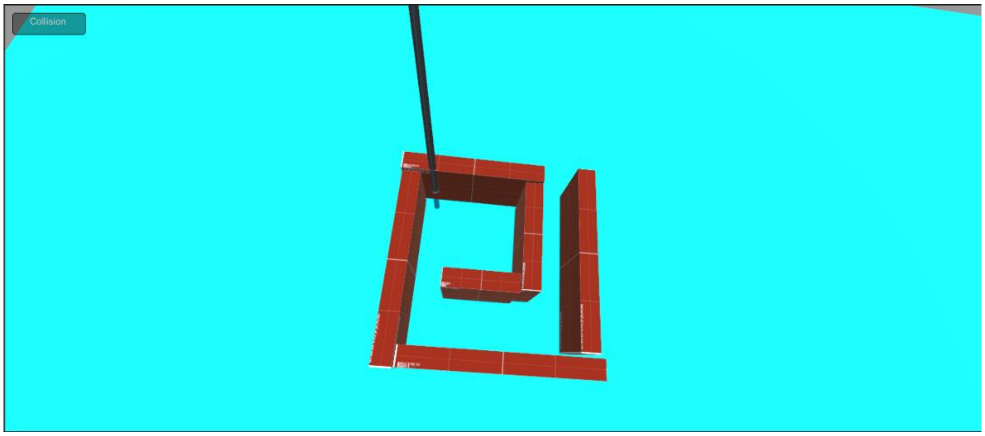
Once all straight-line were found, and all colinear were combined, the equation of all straight lines in a 2d manner is calculated. Using the straight-line backward to filter the raw points. Only raw points close enough to the straight line will be kept. The reason to do that is that the team needs to obtain the correct height of the tools, but the straight lines won't provide this information. Furthermore, more "direct" information will eliminate the error contained in the calculation straight line stage.

3. Obtain the space coordinate of feature point using triangulation method

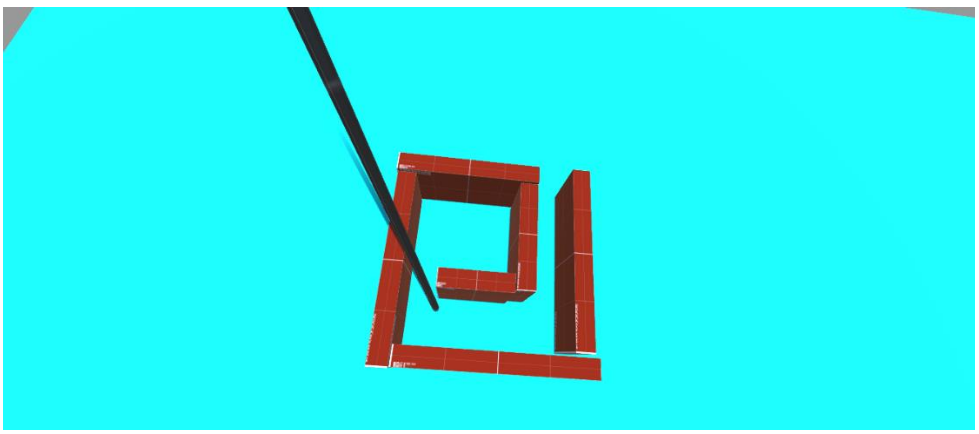
Using epipolar constrain, pixels that are the same height belong to the same pairs. Using the triangulation method to obtain the point cloud of the tool’s “centerline”. Because of the noise, the least square method was applied here to calculate the 3d equation of a straight line. Here we successfully have the position and pose of tools. The accuracy of this technic is great and more than enough for training purposes. Detail will be discussed in the system evaluation section.

The second main part of this system is the UI to display the object. Unity was chosen for this purpose. Several cylinder game objects were created and scaled to the size of endoscopic tools. Using unity build-in collision detection function to detect the collision. The training environment (Currently only a demo) was built within the unity engine.

The connection between the main object detection part and the system UI is based on the ZMQ socket. Using Publish, Subscribe type connection protocol. Main system will detect and publish location information to Unity and Unity will render the tools accordingly. Please refer to graph 7-8 for the current UI and virtual simulation environment setup.



Graph 7:UI shows collision with environment object



Graph 8:UI shows no collision with environment object

System Evaluation and Existing Problems

Team measure 2 aspect of the system. 1. The real time performance of the code. 2. The accuracy of the 3D reconstruction.

1. Real time performance

The performance of the system will vary depending on the resolution of camera images, and the computing power of the processor. Testing environment including 2 types of X86 architecture computer. One equipped with AMD Ryzen 5 5600X processor running at around 4Ghz representing desktop, and the other is equipped with an Intel i7 1165G7 processor running at around 1.5Ghz representing laptop. Both computers are equipped with mainstream hardware in their category, respectively. Currently, using the stereo camera with 1280x720 resolution for each image. The FPS range for localizing 2 endoscopic tools is 40-50FPS on the desktop and 15-20FPS on the laptop. Using the stereo camera with 1344x376 resolution for each image and localizing two tools will achieve 30-40FPS on the laptop. The higher resolution was not evaluated because current stereo cameras have FoV constrain where higher resolution such as 1080p will drop the horizontally FoV from 120 degrees to 90FPS, and it is not ideal for the close-range usage.

The performance of the system might vary in the future, the system was not fully optimized yet.

2. Accuracy

The accuracy of the exact position of handhold tools is hard to measure directly. Hence to check the accuracy, reprojecting the reconstructed 3d point back to the image is a good way. The team can directly measure the pixel level error compared to the original data point. At distance of 20cm from the lens to the object, on the 720P image. The average pixel difference is 1-2 pixels. Based on the given data from the camera, the angular difference is between 0.003-0.006rad. Convert to the distance, the average error is 0.06 cm to 0.12 cm, which is well above the requirement of the training purpose. If using lower resolution for lower-level processor, the error will be increase, but reprojection check has not been performed on low resolution setup.

Existing problems:

The accuracy and robustness of statics image are great, but real-time usage will encounter fluctuation, fluctuation might come from the pipeline is difficult to filter out the error along tools direction.

The multi-tools application needs to be revised due to system doesn't have tools registration and the position and pose were randomly sent to the unity and assigned randomly to the game object.

Unity packing, sending, and unpacking information for multiple tools are required for future development. Current solution will encounter severe delay or packet loss once the tool number increases.

Conclusion and Future Work

In this paper, we propose and implement a demo of the endoscopic surgery training simulator. The system performance and accuracy were evaluated but the system was not finished developed and user studies were not performed yet. The team will continue developing the system and aim to finish the preliminary user study before September.

Our future work includes solving the problem addressed in the "Problem" section including revised algorism, improving the robustness, and unity of the package. Future implementation also including identify the type of tools and using point cloud to reconstruct them. Eventually we want to combined simulator with the Da Vinci Robot.

Management

1. Contribution

Haochen Wei is the only student who works in this project, so all the code, report, presentation and data was created or measured by Haochen Wei

2. Plan VS Real

Please reference the chart for deliverable status.

Deliverable	Planned date	Current status
Minimum Deliverable		
Point clouds of hand-held (and robotic) instruments from sensorized phantom.	3/25	Finished at 3/27
2D video from the perspective of the endoscope output to the standalone monitor.	4/8	Partially Finished at 4/18
Expected Deliverable		
Overlay the patient's 3D model with the obtained point cloud. (Proof of concept).	4/22	Finished at 4/27
Collision detection between the tools and virtual organ model.	4/29	Finished at 4/29

Chart 1: Status of Deliverable

Partially finish reason: The team underestimates the complexity of DVRK and communication between computers that run DVRK and computers running unity. The localizing of endoscopic and integration to the system was not finished.

Please refer to conclusion and future section fur future work.

3. Take Away from the course.

CIS2 is a great and interesting experience that forced me to learn lots of things rapidly. My background was in mechanical engineering, but this project needs lots of coding, and I must pick up some skills that I didn't have. Lacking experience in the different area also brings me problems, lots of difficulties was not considered at the very beginning such as communication between different programs were not considered a problem at the very initial spend lots of time. But it is extremely satisfying that read docs, learn unknown, and construct something that works.

Reference

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Technical Appendix

1. Code

All code was stored on the google drive on following link:
https://drive.google.com/drive/folders/1k3WnxH9BptmxdAbfzAm9MQ4JeIgQkHth?usp=sharing

2. CAD file

CAD file for the basement of stereo camera was store in the same google drive link.

3. README/User Manual

Please reference README in the same repository as code.