Computer-Integrated Surgery II - Project Proposal
Head Mounted Display Integration for Orthopedic Surgery

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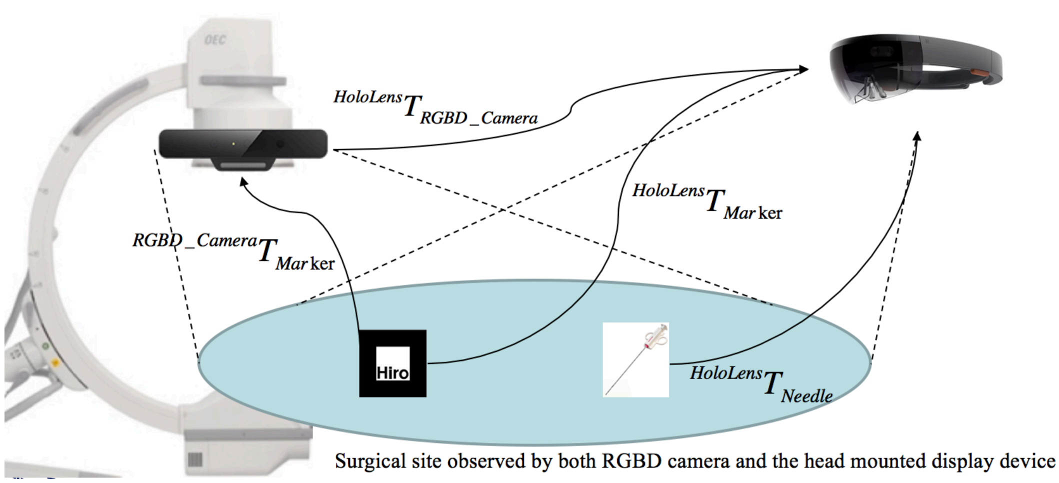
I. Introduction and Background

Orthopedic surgery is the general name of different types of surgery that concern with the musculoskeletal system. It includes treatments to musculoskeletal trauma, spine diseases, infections, tumors and congenital disorders. Orthopedic surgery often requires placing and removing a rigid object during the operations. Therefore, image-guided systems are widely used, especially in minimally invasive orthopedic operations.

Current workflow starts with acquiring multiple X-ray images from different views to locate the point of entry, under the help of a reference tool. Next, the medical instrument is invaded and moved inside the patient's body with small displacements. To determine the direction of the next movements, a set of anteroposterior X-ray images are acquired during each movement, until the target is reached. It could be easily seen that the current procedure produces a large amount of X-ray doses, while with less efficiency on guidance. Low-Efficiency procedure not only frustrates surgeons, but also could cause damages to soft issues and the nervous system, which further lead to severe post-operative sequelae. Therefore, we propose a solution to use HoloLens to display the needle part that is within the patient's body to better guild the surgeon and protect the patient.

The project focuses on using augmented reality to visualize the occluded part of the needle in HoloLens. The whole process also requires tracking the needle position and estimating the needle tip location. The diagram for the system set-up is showed in the graph below. The main hardwares needed for this project are, a RGBD Camera (Intel RealSense SR300) and a HoloLens



Picture 1: System set-up diagram (dashed line shows the field of view)

A RGBD Camera is needed because raw depth data is not available in HoloLens for developers. The camera will be mounted to a C-arm. An important step in setting up the system is to calibrate the camera and HoleLens. The problem is solved by placing a marker in the common surgical site as reference. Camera data will be processed so that the patient model and the tracking marker on the needle could be detected and recognized with known 3D locations. This is crucial because only by knowing the precise 3D locations of both the patient's body and needle, the location of the needle tip with respect to patient's body can be estimated, then the occluded part can be determined. The goals of the project are to accurately track the needle and detect the patient model's body, estimate the needle tip location, and, most importantly, display the occluded part via HoloLens.

II. Technical Summary

The following parts and algorithms will be explored throughout the course. In general, there will be four main parts.

1. Marker Tracking Using ARToolKit
   ARToolKit is an open-source computer tracking library with the ability to create strong augmented reality applications. In this project, it will be mainly used as a recognition and tracking software that can determine the marker's 3D location and orientation for both RGBD camera and HoloLens. The precision of the results will be tested to determine whether or not the ARToolKit is a suitable solution.

2. Patient's Body Detection and Recognition
   A fusion approach will be implemented to determine the patient's skin. All the required RGB data will be provided by the RGBD Camera. Two individual methods are included in this fusion approach. The first is through thresholding the point clouds, which focuses on color image segmentations and was explored by a previous project in 2015. The second approach is through gaussian model, which smooths the whole body surface.

3. Calibrate Cameras on SR300 and HoloLens
   A paper marker is put inside the surgical site observed by both RGBD camera and the head mounted display device (HoleLens). Therefore, the transformations of the marker between the camera and HoloLens, ${}^{SR300}T_{Marker}$ and ${}^{HoloLens}T_{Marker}$ can be obtained by implementing ARToolKit. By compounding the two transformations, the transformation between the camera and HoloLens could be obtained to achieve the calibration process.

4. Display the Occluded Needle Part in HoloLens
   Displaying the needle that is within the patient's skin in HoloLens is an optical see-through problem. It requires aligning the virtual needle accurately with the physical needle. It also requires the virtual needle to follow the physical needle as closely as possible when the needle is moving. Virtual needle's location would be obtained by first comparing patient body's and needle tip's relative positions. Then the resulting occluded part's location could be sent to HoloLens for displaying.

III. Deliverables

Minimum	Roll out HMDs to the hospital operating room
	Camera calibration algorithm for SR300 and HoloLens
	Marker tracking algorithm used to track needle movements
	Skin model detection algorithm with basic thresholding on point clouds
Expected	Needle location and orientation estimation in 3D space
	Algorithms that determines which part of the needle is underneath the patient’s body
	Display the the part of needle that is within the patient’s body in HoloLens
Maximum	Implementation of different perceptual cues
	Evaluation and comparison of different visualizations

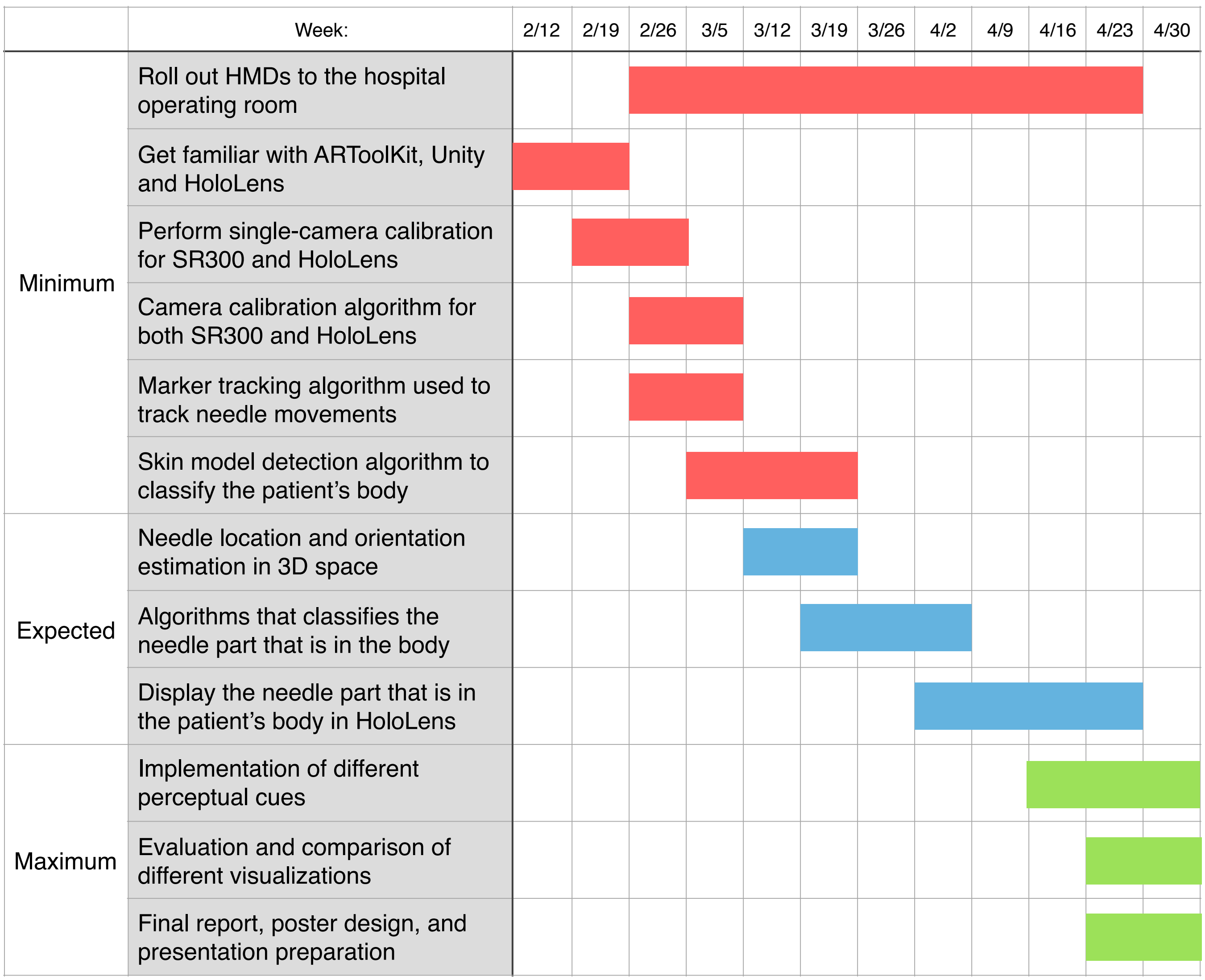
IV. Dependencies

Category	Dependency	Status	Alternative
Hardware	Microsoft HoloLens	Mentor Supplies	N/A
	Intel RealSense SR300	Mentor Supplies	N/A
	C-arm	Mentor Supplies	N/A
	Camera mounts	Mentor Supplies	N/A
	Windows Laptop/Desktop	✓	Mentor Supplies
Software	ARToolKit	✓	N/A
	Visual Studio 2015 Update 3	✓	N/A
	HoloLens Emulator	✓	N/A
	Intel RealSense SR300	✓	N/A
Other	Checkerboard used for calibration	✓	N/A

V. Management

Meeting Schedule		
	Time	Task
Weekly CAMP Meetings	Wednesday 9-10 am	Discuss the progress with Dr. Fuerst and Dr. Navab
Weekly Meeting with Long Qian, Sing Chun Lee, Alexander Barthel and Javad Fotouhi	Friday 3 pm	C-arm related questions: Javad and Sing Chun HMD questions: Long and Alex

VI. Time Table



VII.Milestone Dates

Date	Milestone Description
Feb. 24th	Get familiar with implementing ARToolKit with Unity, and implementing customized HoloLens ARToolKit with HoloLens
Feb. 26th	Start rolling out HMDs to the hospital operating room for advice
Mar. 3rd	Finish camera calibration for Intel RealSense SR300 and HoloLens independently. Save the intrinsic parameters. Start calibration algorithm between SR300 and HoloLens. Start using ARToolKit to track the needle movements. Test using both RGBD camera and HoloLens.
Mar. 10th	Finish calibration process and marker tracking. Start working on detecting and recognizing patient model's body. Start working on solving the estimation of needle tip location and orientation.
Mar. 24th	Finish skin model detection and needle tip location estimation. Start working on classifying which part of the needle is inside the patient's body.
April. 2nd	Finish classifying the needle part that is inside the patient's body. Start to work on visualize the part of needle in HoloLens. Make the virtual needle align with the real needle
April. 16th	Start HMD implementation of different perceptual cues
April. 28th	Finish all the code and algorithm work. Start writing report, poster and evaluating different visualizations

VIII.Supplemental Readings

1. Brand, J., & Mason, J. (n.d.). A comparative assessment of three approaches to pixel-level human skin-detection. Proceedings 15th International Conference on Pattern Recognition. ICPR-2000. doi:10.1109/icpr.2000.905653

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3. Pauly, O., Diotte, B., Fallavollita, P., Weidert, S., Euler, E., & Navab, N. (2015). Machine learning-based augmented reality for improved surgical scene understanding. Computerized Medical Imaging and Graphics, 41, 55–60. doi:10.1016/j.compmedimag.2014.06.007

4. Zhang, Z. (2000). A flexible new technique for camera calibration. IEEE Transactions on Pattern Analysis and Machine Intelligence, 22(11), 1330–1334. doi:10.1109/34.888718

5. Yogarajah, P., Condell, J., Curran, K., McKevitt, P., & Cheddad, A. (2012). A dynamic threshold approach for skin tone detection in colour images. International Journal of Biometrics, 4(1), 38. doi:10.1504/ijbm.2012.044291

6. Robert Discover (2016, April 20). Augmented reality (ARToolkit + unity3D) Retrieved from https://youtu.be/T8O-XKQ2Avo