Wearable Intelligent Navigation System for Surgery

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1 Introduction

The goal of this project is to develop a head mounted display (HMD) for surgeons to use as a navigational aid during a procedure.[1] The WINSS Augmented Reality (AR) system allows for image guided surgery without the need to occupy a surgeon's hands or eyes. Rather than providing high-resolution preoperative images, the HMD will show derived graphics and models, such as tumor outlines and target points in a "picture in picture" manner, to assist in navigation. By using the AR device in conjunction with other sensors for optical tracking and inertial sensing, the system can operate even when markers on the patient frame are occluded from the view of a tracker.

2 Application Components

2.1 Hardware Specifications and Selection

The first step to designing the WINSS was to establish hardware requirements and select between available options. Table 1 shows a description of design criteria, listed in order of decreasing importance.

Table 1: Desired Hardware Specifications

Picture-in-picture	:	The main goal of this project, the HMD must be able to display the desired images in a picture-in-picture format
Able to display from PC software	:	Display must be able to view representations from PC visualization software
Inexpensive	:	~$1000 budget
Field of view	:	HMD must minimally restrict field of view, without creating tunnel vision or distortion of normal vision
Comfortable	:	HMD must be easy to wear, without restricting normal range of motion required for surgery
Camera	:	Use of camera for point tracking in calculating orientation frame
Inertial measurement unit	:	Measurement of motion of head, specifically orientation and movement
Microphone	:	Allow for voice commands and audio feedback to surgeon

Information on different products was obtained from specifications provided by manufacturers as well as through correspondence with technical support staff and developer networks. Based on desired specifications, the three best options were analyzed in Table 2.

Table 2: Analysis of Hardware Options

	Google Glass [2]	Vuzix M100 [3]	Epson Moverio BT-200 [4]
Cost	$1500.00	$999.99 for device $199.99 for developer kit	$699.99
Developer environment	Android SDK with GDK add-on	Android SDK	Android SDK
Capable of picture-in-picture	AR display in top-right corner of FOV	Display in lower corner of FOV	AR display in center of FOV
Able to display from PC software	Pairs with smartphone	Pairs with Android device. Can mirror displays.	Pairs with provided Android handset/touchpad. Can mirror displays via Miracast
Field of view (FOV)	AR display in top-right of FOV	14° AR display in right eye FOV	23° AR display in center of FOV
Comfortable	Glasses-like, wearable headset	Over-ear headset	Glasses-like wearable headset
Inertial measurement unit	Integrated gyroscope and accelerometer	3 DOF head tracking Integrated compass and GPS	Integrated gyroscope, accelerometer, and compass.
Camera	Single camera	Single camera	Single camera
Microphone	Yes	Yes	Yes
Comments	Bone conduction transducer for audio feedback to user	Bluetooth, Wi-Fi connectivity.	Bluetooth, Wi-Fi connectivity. Wearable over glasses.

Based on the analysis of available hardware options, the Epson Moverio BT-200 was selected to be used in this implementation. Even at a lower price than the other options, this device has the same functionalities, such as the ability to create AR views, use of an integrated inertial measurement unit, camera, and Wi-Fi and Bluetooth connectivity. All analyzed options met ergonomic standards and are developed on the Android platform, meaning that any of the above options would be functionally similar.

One notable difference between the Moverio BT-200 and the other options is the display. The Google Glass and the Vuzix M100 have smaller displays in the corner of the FOV, where the Moverio BT-200 has a larger display in the center of the FOV. While this display may seem more obtrusive, the virtual size of the display makes it possible to display the desired models in the corner of the display area and still remain out of the center of the FOV. Looking forward with this project, a center display with separate left and right eye images is capable of producing 3D representations and is thus more conducive to an image overlay system than just a picture-in-picture system.

2.2 System Design

After deciding on a suitable hardware, the layout of the system was developed, deciding how elements and sensors work together to produce the desired outcome.

The WINSS is designed to use on-board instruments to perform tracking and orientation calculations while also interfacing with a PC for heavier calculations and creation of visualizations. The collaboration diagram (Figure 1) provides an overview of how the different elements in the system interact to provide patient and tool tracking to create a visualization of the tool with respect to target areas of the anatomy. The diagram shows that the system makes use of three components on the headset of the Moverio BT-200: the camera, the accelerometer, and the gyroscope. Using the Android handset, changes in position and orientation are calculated in the frame of the headset, and then, camera images and the orientation data are relayed to the PC via Wi-Fi. Using the ArUco [5] marker tracker software package, the location of the surgeon with respect to the patient is calculated. In addition, the Micron optical tracker [6] tracks the positions of the patient and tool, which are used to create a full representation of the positions of all relevant elements in the surgical space. Finally, these positions are related to the CT model to calculate the position of the tool with respect to the target area from the perspective of the surgeon; this representation is relayed back to the headset for the surgeon to see.

Figure 1: Collaboration Diagram

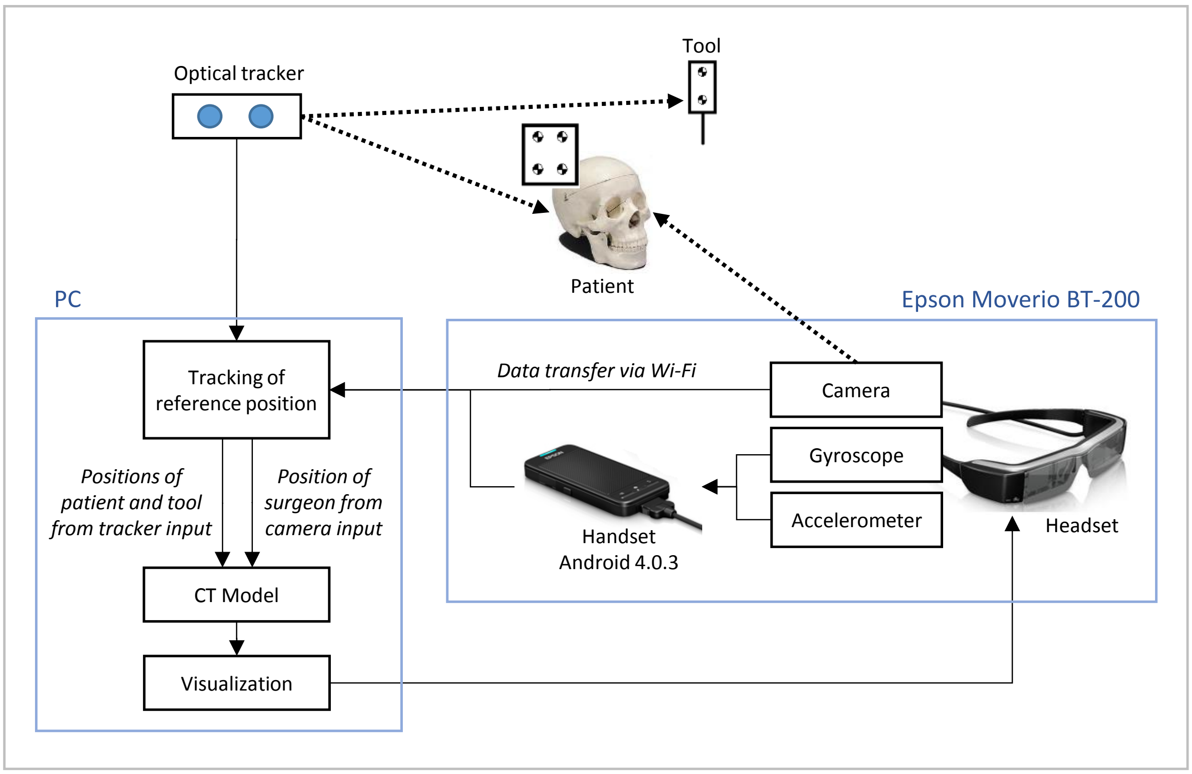
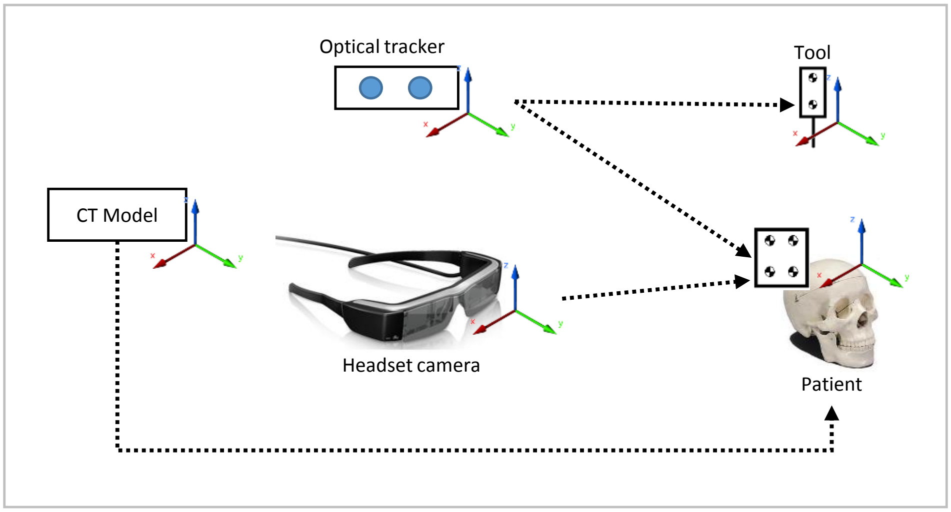


Figure 2 shows the coordinate frames of the major components in the surgical area and transformations between them.

Figure 2: Coordinate Frame Relationships



3 Project

This section provides an overview of the progress made so far on the project, as well as expected outcomes and a timeline for completion of the project. Having studied Android development, sensor use and calculations, solidifying the design of the WINSS, and understanding the use of the ArUco library, the progress made this semester serves as a strong foundation for continuing the project until May 2015.

3.1 Progress

September

The first month of this project was spent researching different hardware products to be used for the WINSS HMD. By reading technical specification sheets and product reviews, studying research projects by other developers, and communicating with technical support staff and developer networks at the respective manufacturers, a tabular summary of the features, advantages, and disadvantages (Table 1) was created. Based on this research, the Epson Moverio BT-200 was bought at the end of the month.

October

The majority of this month was spent studying Android development. First, a development environment was set up using NetBeans [7] with the NBAndroid extension [8]. To practice Android development, sample applications were developed and tested on virtual Android devices. The purpose of these small programs was to develop familiarity with the structure of an Android application, development of user interfaces, XML syntax, and build/install procedures.

After the Moverio BT-200 was delivered, the first goal was to learn how to interface the Android platform with a PC. The Splashtop [9] app provides desktop sharing capabilities from PC to Android with low latency. In an effort to gain direct access to the built-in sensors through hardware wiring rather than software, the Moverio developer network was contacted [10]; however, Epson technical support was not able to provide internal schematics and rather suggested the use of the Android Sensor Service to access sensor information.

November

This month, major progress was made in developing an application for the Moverio BT-200. First, it was necessary to establish a method to install apps on the BT-200. After installing the Android Debug Bridge (ADB) USB driver, which would permit building and installing Android applications with command line arguments, the vendor ID could not be configured properly for the Epson device, meaning the BT-200 was not being detected by the ADB. Thus, an alternate method was found to install applications. When built in the NetBeans IDE, an Android application package (.apk file) is generated. By uploading this file to an online repository, it can be downloaded and installed from the BT-200. This alternate process is advantageous since it is it is both wireless and also manages installation with a few clicks.

Using the Android Sensor Service API, an application was developed to access the accelerometer and gyroscope. Experiments were run to better understand sensor sensitivity, sign conventions from values, and expected values from performed actions. Finally, a Position class was set up to calculate the change in position and orientation of the headset. Using a double integration method of accelerometer values (given zero initial conditions), position values could be calculated. However, the double integration method tends to compound error over time and shows high levels of variability in calculated values. Instead, position will be calculated using the ArUco software package [5] with images obtained from the headset camera. With regard to orientation calculation, it was found that using the gyroscope to calculate orientation yielded more reliable results. Since the orientation calculations are only a single integration of angular velocity about each axis, the calculated values are less prone to the rapid, high magnitude variation that can occur in the accelerometer calculations. Formal experiments have not been conducted to produce quantitative results with regard to the accuracy of the orientation calculations, but will be needed before implementing the calibration algorithm.

3.2 Deliverables

Minimum Deliverables

The minimum expected result of this project is to have the Moverio BT-200 interact with the PC and use the position and orientation calculations to create oriented visualizations of the target area of the anatomy and the tool. This representation would then be able to be seen in the screen of the BT-200 headset, either through an independent application or with a desktop sharing application such as Splashtop (described previously).

Expected Deliverables

The expected deliverables for this project would accomplish the above goals while also implementing measures for the occlusion of markers on either the patient or tool. When a patient marker is out of view of the headset camera, inertial sensing will be used to compensate by calculating changes in motion, using the last position and velocity where all markers were visible as initial conditions. When a patient marker is out of the view of the optical tracker, the view from the BT-200 headset will be used to compensate for the loss of accuracy. In either case, there will be a visible change in the color of the representation to alert the surgeon to the decrease in accuracy of the calculated positions.

Maximum Deliverables

The maximum deliverables for this project would first accomplish the above goals. Then, experiments and mock operations would be performed to test the full extent of the viability of the system in a surgical setting.

3.3 Projected Timeline

This section describes the steps to completing the project over the course of the winter session and spring semester. The table below lists goals and expected deadlines to producing the maximum deliverables described in Section 3.1.

Figure 3: Projected Timeline

	Deadline	Goal
Winter	22 December	Create full software process flowchart
	02 January	Integrate camera into sensor app on Moverio BT-200 headset
	09 January	Set up ArUco tracker software with images from BT-200 camera
	16 January	Establish Wi-Fi data transfer between headset and PC
	30 January	Set up mathematical methods for IMU calculations and calibration algorithm
Spring	13 February	Finish calibration algorithm, with UI elements
	27 February	Set up frame transformations from tracker and headset coordinates to Cartesian space
	20 March	Port existing 3D Slicer module to show visualization on headset
	03 April	Include change in accuracy due to occlusion of markers. Use methods from existing WINSS implementation, which simulates occlusion.
	10 April	Mock operations with WINSS system to test viability in surgical setting

Acknowledgements

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