**600.646 CIS II: Seminar Paper Critical Review**

**Group 7, Zhuokai Zhao – HMD Integration with Orthopedic Surgery**

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## I. Background and Project Overview

Orthopedic surgery is the general name of different types of surgery that concern with musculoskeletal system. It includes treatments to musculoskeletal trauma, spine diseases, infections and tumors. Orthopedic surgery often requires placing and removing a rigid object during the operations.

The project focuses on using augmented reality device HoloLens to visualize the occluded part of the medical instrument using in orthopedic surgeries. The whole process also requires tracking the needle position and estimating the tool tip locations. The main hardware needed besides HoloLens is a RGBD camera (Intel SR300) and a Windows laptop.

## II. Paper Selection

Two paper are selected. The first one is “Hybrid In-Situ Visualization Method for Improving Multi-Sensory Depth Perception in Medical Augmented Reality” [1] and was published on ISMAR in 2007. The second one is, “Virtual Extended Surgical Drilling Device: Virtual Mirror for Navigated Spine Surgery”, [2] and was published in the same year on MICCAI. Both were first-authored by Christoph Bichlmeier, a member of Computer Aided Medical Procedures (CAMP).

The first paper focuses on solving the misleading perception of depth and spatial layout problems in medical Augmented Reality. It provides different types of visualization clues (transparency, shadows, etc.), which will be very useful to my project concerning the visualization options.

The second paper introduces a new virtual mirror method for navigated spine surgery using a stereoscopic video see-through head-mounted display (HMD) and an optical tracking system. Although the virtual mirror approach is unlikely to be implemented in my project, it is a different and valuable experiment to study.

## III. First Paper Critical Review

### a. Summary of Problem and Key Results

As mentioned above, the paper handles the problem of misleading perception of depth and spatial layout in medical Augmented Reality. The problems are important because the superimposed virtual objects without special visualization cues usually seem to be in front of the patient. Below shows an example of the misrepresentation, where the spine seems to be floating above the skin mode.

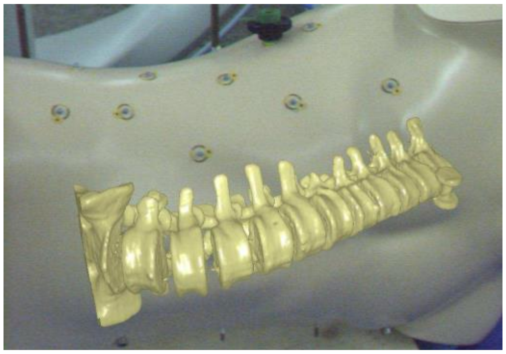

Figure 1: Superimposed spinal column seems to be in front of the patient

The paper presents a new method for medical in-situ visualization. The new method allows for improved perception of 3D medical data. It also helps navigate surgical instruments relative to the patient's anatomy.

## b. Background

Being able to see into a living human system largely improves medical diagnosis and reduces invasive surgeries. Starting from the inventions of Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and Ultrasound Imaging (UI), many approaches have been made through generations of researchers [3, 4]. In terms of visualization, Bruckner et al presented a context preserving volume rendering model [5], which emphasized on transparency effects. Later, Krueger et al came up with a "ClearView Method", which further added shading on the existing transparency [6]. They also used a painted ring to highlight the area around the region of interest.

## c. Method Description

The system set-up includes two synchronized tracking systems – the single camera inside-out tracking system mounted on HMD and the infrared-camera optical outside-in tracking system fixed in the room. The diagram of this system is showed below.

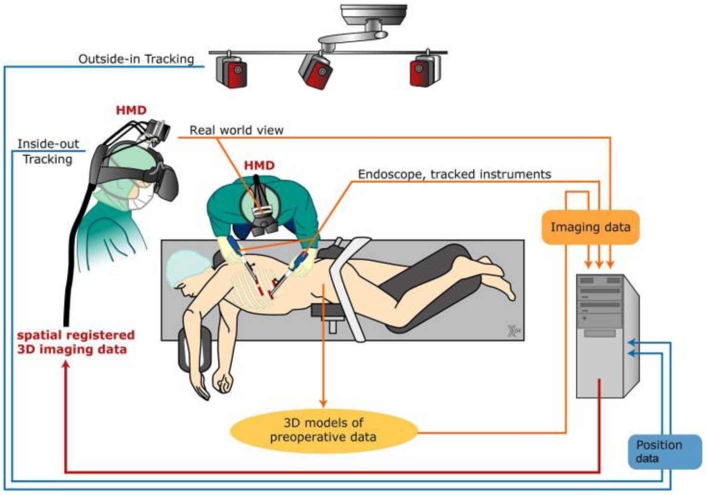

Figure 2: Overview of the system set-up

In this set-up, the inside-out system tracks the movement of the HMD with respect to a reference frame, which is also tracked by the external outside-in system. The common-seen reference frame then enables the transformation between the inside-out and the outside-in tracking systems. Therefore, all target positions obtained through the external outside-in tracking system, ${}^{target}T_{ext}$, could be transformed to be with respect to the reference frame of the inside-out tracking system, ${}^{target}T_{ref}$, by calculating

$${}^{target}T_{ref} = {}^{target}T_{ext} \cdot ({}^{ref}T_{ext})^{-1}$$

Similarly, the transformation of volumetric medical imaging data ${}^{CT}T_{ref}$ with respect to the reference frame could be obtained by

$${}^{CT}T_{ref} = {}^{CT}T \cdot {}^{patient}T_{ext} \cdot \left({}^{ref}T_{ext}\right)^{-1}$$

The core method of this paper is a new technique that manipulates the transparency of the camera images as a function of the geometry of patient skin and the line of sight of the HMD user/observer. To start, the author divided the patient skin surface into two domains; “TransDom” and “OpaDom”. As their names suggest, TransDom includes transparent and semi-transparent skin within the vision. On the other hand, OpaDom represents the opaque skin outside the vision. Three parameters are responsible for calculating the transparency factor used to determine the two domains; curvature, angle of incidence factor and distance falloff.

Curvature represent the curvature situation around a specific 3D position on the patient skin model. It is calculated through the below equation:

$$curv = 1-(1-\frac{\sum_{n_i \in N} \|\vec{n}-\vec{n}_i\|}{2\cdot|N|})^{a}$$

where $\vec{n}$ is the normal vector of the targeting vertex of the skin surface, $\vec{n}_i$ is the normal vector of all neighboring vertices, and $a$ is a user-defined parameter to modify the result interactively. The higher the curvature value, the opaquer of the surface region.

Angle of Incidence Factor is the angle between the vector pointing from the user/observer’s eye position and the normal vector $\vec{n}$ of the skin surface. It is calculated as:

$$angOfInci = 1-(\vec{n}\cdot\vec{v})^{\beta}$$

where $\vec{v}$ is the vector pointing from the eye position. The smaller the angle of incidence factor, the lower opacity of the surface region.

Distance Falloff is the distance between each single surface fragment and the intersection fragment of the line of sight and the skin surface. The falloff function enables a smooth border between the TransDom and OpaDom and is calculated as:

$$distFalloff = (saturate(\frac{distToViewIntersecPoint}{radiusOfTransparentRegion}))^{\gamma}$$

where “saturate” is a function that clamps its input to [0, 1]. Intuitively, the larger the distance falloff value, the less transparent of the surface.

The final transparency value is calculated by weighting the three parameters introduced above by $w_1, w_2$ and $w_3$:

$$opacity = saturate(\max(w_1 \cdot curv, w_2 \cdot angOfInci, w_3 \cdot distFalloff))$$

## d. Results

The experiments include three different of types: cadaver, phantom and in-vivo study. Each of the resulting graph is showed below.

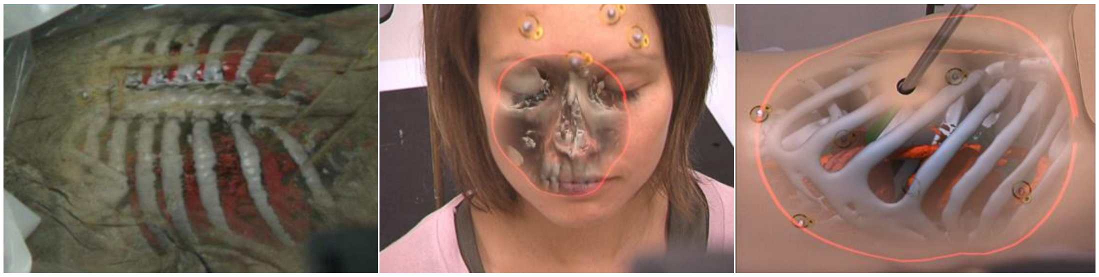

Figure 3: Results of the presented method

## e. Discussion and Assessment

The paper has provided a new method for surface detection and transparency rendering, which could be a great reference example of my project. However, it has its limitation that the surface models have to be segmented, triangulated and smoothed before the visualization. This disadvantage limits its usability in an operation room.

Another limitation is that it is a video see-through system, which means that there is a delay between the user’s video vision and the real world. This is not a significant factor during normal conditions, but could be a great factor when there is an urgent situation, for example, hemorrhoea, happening.

Possible next steps would include rendering CT/MRI data in real-time without preparative steps, deeper visualization for regions hidden by bones and tissues, and more effects about textures, ridges and valley lines on visualization.

### f. Conclusions

The paper provides a great approach on modifying the transparency of video images recoded by a video see-through head-mounted display device. In their approach, different viewing geometries of the observer and skin surface have different transparency effects, which is a new method of the medical imaging visualization field. It also describes a method for integrating surgical tools to improve navigation in medical augmented reality. But the adding tool method is just a beginning and is not as advanced as the surface processing method.

## IV. Second Paper Critical Review

### a. Summary of Problem and Key Results

In spine surgery, implantation of pedicle screws is often performed, which requires imaging guidance system. State-of-the-art system presents the imaging data with three orthogonal slice views on an external monitor in the operation site, which is not perfect as it requires mental mapping from the surgeon.

This paper introduces a new virtual mirror method that uses a stereoscopic video see-through head-mounted display (HMD) and an optical tracking system to navigate the spine surgery. The main advantage is that the mental mapping of medical imagery is no longer necessary.

### b. Background

During the last decade, intra-operative augmented reality visualization and navigation has been an intensive and popular research project. Azar presented a user performance analysis and determined that a HMD device was the better solution in avoiding the surrounding structures and finishing in a shorter time [7]. Later, Navab introduced the laparoscopic virtual mirror for liver resection [8].

### c. Method Description

The system set-up includes two synchronized tracking systems, which are the same as the systems introduced in the first paper. Therefore, I am not repeating everything here again. As described, all augmentations are positioned with respective to the reference frame of the inside-out system. The transformation for in-situ visualization, ${}^{CT}H_{ref}$ , is:

$${}^{CT}H_{ref} = {}^{CT}H_{phantom} \cdot {}^{phantom}H_{ext} \cdot ({}^{ref}H_{ext})^{-1}$$

The phantom was built with three vertebrae embedded in a silicone mold. The design of silicone mold avoided multiple scans for every new experiment. During the experiment, the silicone mold that holds the three vertebrae would be installed into a wooden box filled with peas to simulate a restricted view for surgeons as in the real scenario.

The integration of virtual mirror, which is the most important part of this paper, was divided into two steps; planning and drilling. A red arrow, positioned at the tool tip, is orientated to the drill direction. In the planning procedure, the surgeon moves the drill and orientates the red arrow to the optimal drill canal. During the movements, the virtual mirror provides side views of the semi-transparent vertebrae. Surgeons could change the mirror position by rotating the drill device round its axes, as showed in the graphs below.

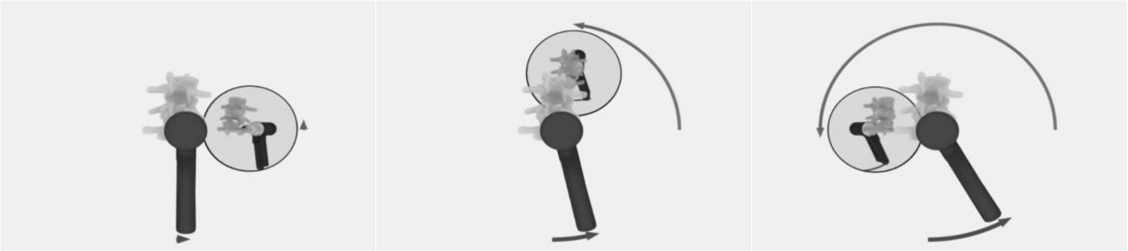

Figure 4: Change the mirror location by rotating the drill

When the canal is positioned correctly, the canal could be locked.

During the drilling process, once the canal is locked, the mirror would automatically go to a position where is orthogonally in front of the drill direction. Surgeons are expected to move the mirror it their preferred locations. A virtual spot light, attached to the drill tip, will remain to represent the drilling direction. Spot light is not blocked by any drilled objects. Therefore, it illuminates the whole path, including the entry point, and the exit point on the other side of the vertebrae. The complete effects are showed in the graphs below.

Figure 5: Experiment graphs

## d. Results

The experiments include 5 surgeons, each drilling 8 canals. The results regarding the drilling accuracy and time are summarized in the table below.

| | Method | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Accuracy (mm) /Time (s) | Virtual Mirror | 1.35/173.75 | 0.75/84.13 | 0.17/18.81 |
| | Monitor Based | 1.7/168.95 | 0.86/103.59 | 0.19/23.16 |

Table 1: Experiment results

### e. Discussion and Assessment

The present method, virtual mirror, provides a more intuitive visualization and more accurate navigation, compared to the classic method. Although it is unlikely to be implement virtual mirror in my project, it is a different and valuable approach to study.

The disadvantage of this paper is obvious as well. It provides too few experiments. Five surgeons, each drilling 8 canals, are not enough to draw a valid statistically conclusion. Further, although it is more accurate than the classic method, it is slower. Future work will include inviting more surgeons to do the experiments.

### f. Conclusions

The paper introduces a new method for navigated spine surgery using augmented reality technology. Although it has its limitations, which are discussed above, it is a successful approach to support more intuitive visualization and more accurate navigation.

## V. References

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