CIS 2 Seminar Summary Paper

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Paper: Contribution of Augmented Reality to Minimally Invasive Computer-Assisted Cranial Base Surgery

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Introduction

The past two decades has seen the emergence of augmented reality technology. While it has gained immense popularity, its potential use in the operating room is still under development. Augmented reality is defined as being an interactive environment where physical objects in the real world are augmented by computer graphical virtual objects in the virtual space. There are two different types of augmented reality delivery, immersive and semi-immersive. Semi-immersive technology involves having the user partially disconnected from reality, whereas immersive technology involves the user having a direct view of reality with some virtual features projected over the environment.

AR can be delivered through a variety of different methods in the operating room. These include, googles, screens, loud-speakers, joysticks, and robots. The chief target of these systems in the operating room are to provide usefulness to the surgeon by ergonomically providing reliable information about the operation at hand. Any of these image-guided surgical systems are based on three core principles, localization, orientation, and navigation. Localization involves identifying a surgical target, like a tumor etc. Orientation involves determining the relationship between the patient and the surgical instruments being used. Navigation involves guiding the instruments correctly to the patient.

This paper is a review of 45 different studies that have utilized AR in the development of new surgical techniques. The cranial base surgical (CBS) domain was the authors' primary target. Since the CBS involves a broad range of different surgical techniques within one procedure, applying AR technology will involve understand all of the surgical nuances that are posed by the procedure. The procedure involves rhinology, otology, and neurology, to name a few. What makes the procedure inherently difficult is the location of particularly sensitive anatomy in the surgical space. This includes nerves, arteries, and brain tissue itself. Additionally, surgeons must also re-establish aesthetics and functional anatomy as a part of the procedure. Usually the surgery is approached through nasal cavities by using rigid endoscopes inserted through the nostrils. The surgeon views the operative field through a computer screen and must have a fine knowledge of anatomical landmarks in order to operate effectively. Unfortunately, these landmarks are difficult to identify as blood and other fluids can be blocking the surgeons view. Thus, an AR surgical system could provide significant information to the surgeon that would be paramount in improving patient outcomes.

The paper goes on to examine different AR systems and current techniques used to develop these systems.

Calibration

Calibration is one the most important aspects of developing an AR system. The basic function of the calibration is to understand the accuracy of the instruments used in the surgical environment. Every computer-assisted surgical system involves a robust calibration procedure to ensure the accuracy of the system. Early AR systems utilized fiducial registration to complete the calibration. The basic idea of the calibration process is to use some real-world feature as reference to your system in order to determine if the computer's idea of the location of the instruments is accurate. The utilization of marker frames has been shown to provide good accuracies, but the issue with these systems, is that they involve the introduction of external equipment that could limit the instrument maneuverability in the system. The paper points out the immense care that must be taken for the calibration process because of the strict accuracy requirements involved in CBS.

Registration

The primary step in any AR surgical system is the registration process. The goal of which is to establish correspondence between the different objects and instruments involved in the system. The process of registration establishes all of the components of the systems into a single coordinate system. The most commonly used registration methods have been point-based registration and contour-based registration. Anatomical landmarks have been used in the past to establish patient-image relationships, but the issue with these systems is that anatomical landmarks are difficult to track and can shift or be blocked during the procedure.

Artificial markers on a pre-operative scan of the patient have been suggested as an alternate option, but the issue with these systems is that the pre-operative scans usually take place hours if not days before the actual procedure, which allows time for shifting and other issues. A common other option is to attach the skull to a Mayfield clamp, a commonly used head clamp used to keep the patient in place and attach a reference frame to it. However, these frames introduce difficulties in surgeon movement and tool manipulation. Contour based methods involve a matching process between virtual contours and real ones. This usually involves an iterative closest point algorithm or analogous computational process.

With all this said, the best approach seems to be integrating both contour-based and point based registration processes into one approach.

Motion Tracking

Having completed registration, the next important step involves tracking the movements of surgical instruments in the operative field. When deciding on a tracking system to utilize, the paper points out that there are specific considerations that must be considered. The number of devices that need to be tracked, the refresh rate of the tracker, the size of the operative field, the robustness of the accuracy needed, and nature of the interaction of the markers in the operative environment. Optical trackers have seen the most success in the field. They have shown to have the highest precision.

Visualization Devices

There have been a variety of different options explored for visualizing information for the surgeon in the domain of AR systems. The most popular display in the CBS domain has been the traditional surgical monitor. The main advantage of such systems is that multiple people within the operating room are able to see the visualizations displayed to the surgeon. The issue of systems like these, is that they involve the surgeon having to rotate back and forth from the patient to the monitors in order to complete the procedure. This can be very uncomfortable for the surgeon and can lead to adverse complications for the surgeon in the long term. Tablets have also been used; however, these systems are not great for visualization of small anatomical features as they have not been accurate in previous systems. One other major disadvantage of these systems is the lack of depth cue in the visualization. The surgeon has to extrapolate from the 2D view shown in the monitors, the 3D orientation of the anatomy and location of surgical instruments.

As an alternative to these systems, 3D displays have been proposed to combat the issues that plague the traditional surgical display. It is important to note that it has been shown that it is not ergonomic to have virtual objects constantly displayed in the operative field as it prevents the surgeon from view the critical anatomy of the patient. HMDs or head mounted displays have been proposed as a promising alternative. Up until now, these systems have only seen use in cranio-maxillofacial domain which does not involve interaction with deep surgical areas. Binocular HMD systems have seen the best performance in these systems when compared to singular HMDS. In fact, binocular HMDs have been shown to have an average of 35% better accuracy and time in comparison to monoscopic HMDS. While HMD technology seems promising, they also have their issues. One involves the inattentional blindness of the surgeon of full visible but unexpected objects in the operative field due to distraction from the virtual features also present in their view. Additionally, surgeons have had problems with focusing the virtual objects in the correct locations in the operative field. Latency has also been a major problem that cannot be tolerated in the surgical environment.

Experimental Validation

The commercially available AR systems in use currently have seen target accuracies achieved at around 1.5-2mm. However, in the surgical domain these accuracies usually drop below this threshold. Researchers have shown that with current technology, accuracy in the sub-mm range is infeasible. It is important to note that in surgical applications, the laboratory studies that have been done on these AR systems have not had comparable results. There are numerous different factors that have prevented this from occurring. From laboratory to actual operation, the difference in accuracy drops by 45%. First fiducial registration error can occur. Target registration error can also be affected. Additionally, the difference between real world objects and virtual object overlays can have a registration error. Error in the determination of surgical tool locations can also be a factor. In order to have successful outcomes, it is critical that in the CBS domain that all of the errors listed above be less then 1mm.

Conclusion

Having discussed the technical details involved in the implementation of an AR system, the paper suggests the following requirements in order to have an effective, functional AR system. After reviewing 45 different studies, the authors concluded that the following features are necessary in the development of an AR system for use in CBS.

- Having a simple installation procedure and set up process.
- As minimum a calibration process as possible.
- High system accuracy.
- Short registration time, 5-10 min.
- Low latency and high resolution and frame rate.
- Depth cues for 3D visualization.
- Virtual objects only present when necessary.
- Common visual focus between virtual objects and the real world.

The paper concludes by stating that 85% of surgical residents preferred the integration of AR into their residency programs and 93% approved of their use in the operating room. This makes the field promising in the future and now.

Assessment

Overall the paper is a good review of the application of AR systems in surgical procedures similar to our project. It also provides good information on how to create such an effective system. It could have been better if there were more specific details on which of the many AR systems analyzed were the most successful. Overall, the paper has high importance in the field of augmented reality surgical systems.

Citation

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