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Assessment of using Computer Vision and Augmented Reality for Improved Minimally Invasive Spinal Procedures

Jingwen Hui, Songyuan Lu, Eric Lee, and Frank E. Talke
Center for Memory and Recording Research (CMRR), University of California San Diego
jwhui@ucsd.edu; sol025@ucsd.edu; es1003@ucsd.edu; ftalke@ucsd.edu

Abstract **-** Computer-assisted surgical navigation techniques have become increasingly more important in healthcare. Navigation systems are designed to improve surgical accuracy, safety, and efficiency for various invasive procedures. In this paper, we design a low-cost 3D navigation system utilizing augmented reality (AR) and computer vision (CV) for pain management of spinal procedures such as radiofrequency ablation (RFA) and epidural steroid injection (ESI). Simulated spinal injection experiments are performed and the accuracy of the proposed AR approach is assessed. The results show that augmented reality is a useful tool in surgical navigation and can serve as a cost-effective alternative to fluoroscopy.

Keywords**:** Augmented Reality, Computer Vision, Biomedical Devices

1. Introduction

Surgical operations rely on the 3D positions of surgical instruments relative to anatomical features. Surgical tracking is essential for improving the accuracy of various procedures. Most healthcare facilities use fluoroscopy, a method employing X-rays to capture real live images in a specified body region [1]. An application where fluoroscopy finds extensive use is in pain management and spinal surgery [2]. Here, two techniques are used primarily, namely, radiofrequency ablation (RFA) and epidural steroid injection (ESI). In RFA, a radiofrequency needle transmits heat to injured nerves, providing long-lasting pain relief [3]. In ESI, inflamed spinal roots are treated by injection of anti-inflammatory medication such as steroids or corticosteroids [4]. Regardless of the technique employed by physicians, both methods involve the use of fluoroscopy to guide needles to specific anatomical locations. Repeated exposure to radiation poses significant risks for both, the patients and the medical doctors, ranging from skin rash to organ necrosis [5].

Recent applications of augmented reality (AR) in healthcare have revolutionized surgical procedures [6]. For instance, Molina et al. [7] have performed AR surgeries, enabling the localization of bones and soft tissues in living patients.

The Use of AR In Back Pain Management

In this paper, we design a low-cost 3D navigation system utilizing augmented reality (AR) and computer vision (CV). Our approach consists of the following conceptual steps. We first create a 3D model of the surgical region of interest from MRI scans and convert this 3D model into a virtual model. We then display this virtual model on the surgical region of interest using augmented reality goggles and registration markers (ArUco markers) on the patient's spinal position. Thus, when viewing the surgical region of interest via AR, the surgeon sees not only the surface of the patient but also the internal anatomy below the surface. Due to the limited access to patient MRI data, we have generated a phantom spinal model (for testing) using 3D printing and computer-aided design (CAD). Employing CV technologies and ArUco markers to track the patient position, we overlay the virtual image on the patient using augmented reality. A schematic of our approach is shown in Figure 1. Here, the CAD model of the spine is shown in Fig. 1a. The virtual image of Fig. 1a is shown in Fig. 1b, to be overlayed onto the test subject. The position of the patient is tracked in real-time using ArUco markers, stereoscopic cameras (Logitech C920x HD Pro Webcams) and Vuforia, a 3D AR software development kit (Fig. 1c). The schematic of the system is shown in Fig. 1d, including the surgeon with AR goggles, the patients, and the ArUco marker registrations.

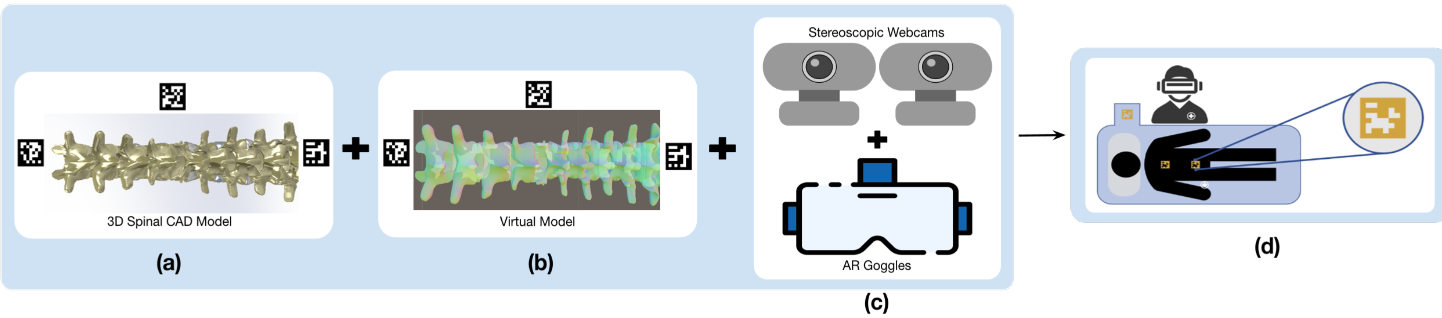

Fig. 1: Augmented reality approach for minimally invasive spinal procedures. a) 3D spinal CAD model. b) Virtual spinal model. c) Stereoscopic cameras and AR goggles for display of virtual spinal model. d) complete set-up

2. Materials and Methods

The new design approach used in this paper eliminates the dependence on fluoroscopy during pain management surgical navigation. To evaluate the benefits of this approach over traditional methods, we have performed experiments to study the reliability and success rate of finding a described location on a specially designed spinal model with and without the use of AR.

2.1. Spinal Model Design

In Fig. 2 we show the schematic of spinal model used for the evaluation of AR in spinal surgeries. The model consists of a 3D-printed stereolithographic spine segment with three vertebrae, encased in a 160mm x 160mm x 100mm ballistic gel rectangular prism. The model was marked at two locations to provide a target for needle insertion. A feedback detection mechanism was implemented to indicate if the needle was placed within the target region during an experiment. The operator would aim with the tip of the needle to the center red dot which represent the medial branch nerve, a common target in pain management procedures [8]. During experiments, the model will be positioned vertically, with its top surface covered to restrict the operator's vision of the model.

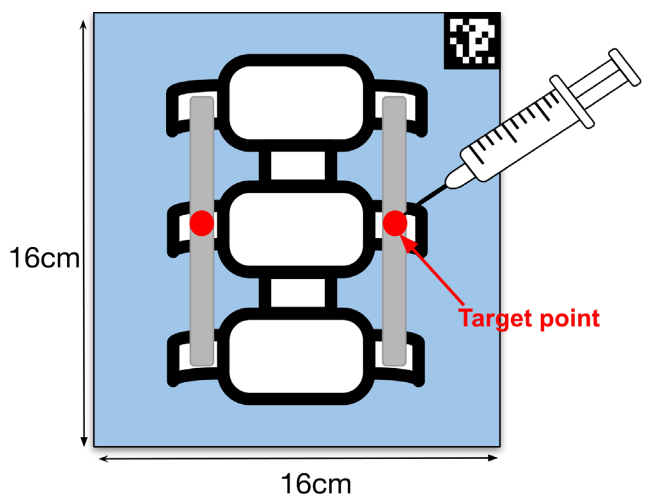

Fig. 2: Spinal Model Design schematic.

2.2. Software

We have used an AR 3D platform (Unity) to build the AR environment. An AR 3D software development package (Vuforia) was used for the detection of the ArUco markers. The open-source spinal model that was used to construct the physical model was converted to an AR object in Unity. The position of the model was tracked in real-time using stereoscopic cameras (Logitech C920x HD Pro Webcams) coupled with Vuforia, which facilitates the generation and overlay of the virtual spinal model onto the physical one. The AR environment and the overlaid model were viewed through a commercially available headset (Meta Quest 3, Meta Platforms) utilizing the Quest Link feature to display the simulation. The overlaid AR model provides operators with visual augmentation during experiments.

2.3. Experimental Setup/Detection Feedback

A total of 40 insertion trials were performed, 20 using AR and 20 without AR or fluoroscopy. A successful trial is defined as one in which the needle strikes the 15mm wide tape on the middle vertebrae, leaving a mark. We analyzed the success rate and average deviation from the target for both sets of trials using Eqs. (1-2).

$$\text{Success Rate} = \left(\frac{Spots\ found\ on\ tape}{20}\right) \times 100\% \quad (1)$$

$$\text{Average deviation} = \frac{\sum(All\ distance\ from\ center\ of\ redline)}{Spots\ on\ tape} \quad (2)$$

3. Results

We have divided our results into two sections to assess the accuracy and misplacement distance of our AR system (Table 1).

Table 1: Experimental Success Rates and Average Deviations With VS Without AR system

	Without AR System	**With AR System**
Success Rates	45%	85%
Average Deviation	0.51cm	0.28cm

Table 1 shows that the use of the AR system increases the experimental success rate from 45% to 85%, and reduce the average deviation from 0.51 cm to 0.28 cm.

4. Discussion/Conclusion

In this paper we have investigated the use of a cost-effective, radiation-free surgical navigation system for minimally invasive spinal pain management procedures by leveraging AR and CV. The result shows that AR is a useful tool in surgical navigation and serves as a cost-effective alternative to fluoroscopy. Our AR experimental result on a 3-vertebrae model shows an increase in accuracy and a decrease in the deviation distance as compared to the case where AR is not used. With a $600 AR system and open-source modelling files, our study shows the potential of significant cost savings using AR. Furthermore, AR usage eliminates radiation damage, ensuring a safer environment for both hospital staff and patients.

While our results with a $600 AR system and open-source modelling files are promising, further research is needed to achieve accuracy levels near 100%, as experienced with fluoroscopy. This includes the development and integration of trackable surgical instruments, enabling surgeons to visualize spatial positioning of their tools relative to the spine of the patient. In addition, future experiments should involve human-like models. That is to say, the model should contain all important anatomical features, such as ligaments, hip anatomy, and natural spinal curvature. Recurrent neural networks (RNN) should be incorporated to further refine computer tracking accuracy [9], aiming to reduce the deviation to less than 0.14 cm, a value accepted as error for radiofrequency ablation procedures [10]. We believe that the augmented reality approach investigated in this paper will find application in minimally invasive pain management surgeries in small to midsize healthcare facilities.

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