



DEVELOPMENT OF A HIGHLIGHTING SYSTEM FOR SURGICAL INSTRUMENTS IN TOTAL KNEE ARTHROPLASTY

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Abstract : Total knee arthroplasty is a complex surgical procedure where precise identification and handling of surgical instruments are crucial for successful outcomes. However, during surgery, the visibility of instruments can be compromised due to poor lighting and distractions, which increases the risk of surgical errors. This project proposes the development of an intelligent highlighting system to improve instrument tracking and visibility during Total Knee Arthroplasty. The system utilizes computer vision and real-time image processing to detect and highlight instruments, enhancing surgical efficiency and accuracy. The goal is to provide a reliable tool to assist surgeons in easily identifying and locating instruments, reducing the likelihood of errors and improving overall surgical performance. The proposed system integrates seamlessly with existing surgical setups, ensuring minimal disruption. Key advantages include improved safety, reduced time spent searching for instruments, and enhanced surgical precision.

IndexTerms - Total Knee Arthroplasty, Surgical Instruments, Computer Vision, Real-time Image Processing, Surgical Safety, Instrument Tracking, Surgical Precision.

I INTRODUCTION

Total Knee Arthroplasty is a widely performed surgical procedure aimed at relieving pain and restoring function in patients with advanced knee joint arthritis or other debilitating conditions. The surgery involves the replacement of the damaged knee joint with a prosthetic implant. Over the years, Total Knee Arthroplasty has become a highly effective treatment for individuals suffering from knee joint pain [1] and immobility. However, the success of the surgery is not solely dependent on the surgeon's expertise but also on the proper handling and identification of surgical instruments during the procedure. In many cases, surgical instruments are spread out on the operating table, making it difficult for the surgeon to quickly locate and use them, which can lead to inefficiencies and errors. Additionally, low lighting or distractions in the operating room can further impair the surgeon's ability to track and identify the required instruments. As a result, there is an increased risk of delays, complications, and even mistakes that could affect the overall outcome of the surgery.

The challenges faced in the operating room highlight the need for an innovative solution to improve the visibility and accessibility of surgical instruments during Total Knee Arthroplasty. Traditional methods, such as manually organizing instruments or relying on a surgical assistant to hand over tools, have their limitations [2], especially in fast-paced surgeries. In recent years, there has been growing interest in utilizing technology to enhance the surgical environment. Among these technological advancements, computer vision and real-time image processing have shown great promise in improving surgical outcomes by providing automatic tracking and highlighting of surgical instruments. This technology can potentially assist the surgeon by making instruments more visible and easier to locate, thus improving the overall efficiency and safety of the procedure.

The proposed solution for this issue involves the development of an intelligent highlighting system that uses computer vision to detect and visually emphasize the surgical instruments during Total Knee Arthroplasty. The system would work by capturing real-time images or video of the operating [3] table and processing them to identify instruments based on shape, color, or other visual markers. Once detected, the system would apply highlights, such as brightening or outlining, to the identified instruments, making them more visible to the surgeon. This would not only aid in instrument recognition but also reduce the time spent searching for tools, thereby increasing the speed and efficiency of the procedure.

In addition to improving instrument visibility, this system could enhance safety by reducing the likelihood of surgical errors. A common problem during surgery is the accidental misplacement or mishandling of instruments, which can lead to complications or delays. By making instruments [4] more visible and easily identifiable, the system reduces the chances of such mistakes. Moreover, since the system operates in real-time, it can respond immediately to changes in the surgical environment, ensuring that the surgeon always has the necessary tools at hand.

The primary goal of this project is to provide a reliable and efficient tool that can seamlessly integrate into existing surgical workflows. The highlighting system should be easy to use, non-invasive, and minimally disruptive to the surgical team. By addressing the challenges related to instrument visibility [5], the system aims to contribute to a safer, more efficient, and successful Total Knee Arthroplasty procedure. The benefits of implementing this system include improved surgical precision, reduced risk of errors, enhanced patient outcomes, and overall time savings during surgery. With further development and refinement, this technology could be expanded to other surgical fields, offering significant improvements in a wide range of medical procedures.

This work is organized as Section II presenting a review of the literature survey. Section III describes the methodology, highlighting its key features and functionality. Section IV discusses the results, analysing the system's effectiveness. Lastly, Section V concludes with the main findings and explores future implications.

II LITERATURE SURVEY

The importance of instrument visibility in surgery has been widely recognized, with various methods being proposed to enhance the efficiency of surgical procedures. Technological advancements, particularly in computer vision and real-time image processing, have provided innovative solutions to this issue. One approach is the use of automated tracking systems, which can detect and highlight instruments, ensuring they remain visible during the procedure. These systems offer an efficient way to reduce delays in finding instruments and mitigate the risks of errors caused by poor visibility. Their integration into surgical settings promises to improve overall safety and efficiency. Recent studies have shown that poor lighting and the disorganization of surgical instruments can lead to significant inefficiencies in operating rooms. In Total Knee Arthroplasty [6], this issue is even more critical, as surgeons need precise control over multiple tools. Researchers have focused on integrating computer vision and machine learning techniques to automatically identify instruments and track their movements. These technologies are designed to assist surgeons in quickly locating tools, minimizing the time spent searching for them. By ensuring that instruments are always visible, these systems can enhance procedural speed and reduce the chances of mistakes.

In recent years, image processing techniques have been applied in surgical settings to improve the visibility of instruments and facilitate faster decision-making. Several studies have highlighted the potential of real-time visual tracking in complex procedures, where maintaining a clear overview of the surgical area is essential. These systems work by using cameras to [7] capture high-definition images of the operating table and applying algorithms to identify instruments. Once detected, the system can highlight these instruments, making them more visible to the surgeon. This technology has shown promise in improving surgical workflow and safety by providing enhanced instrument visibility.

The application of augmented reality (AR) in surgery is another area that has gained attention for improving instrument visibility. AR technology can overlay computer-generated images onto the surgeon's field of view, providing real-time information [8] about the location of instruments. This technique is particularly useful during surgeries where instruments are often scattered across the operating table, as it enables surgeons to identify tools quickly without distraction. By enhancing the accuracy of instrument placement and reducing the risk of errors, AR-based systems contribute to a safer and more efficient surgical environment, especially in Total Knee Arthroplasty procedures. Studies have demonstrated the potential benefits of using robotic systems to assist in surgery. These systems can enhance instrument control and precision [9] while reducing the physical strain on surgeons. Robotic-assisted surgeries often rely on sophisticated cameras and computer vision technologies to provide real-time feedback on the positioning of surgical instruments. By highlighting instruments and guiding their movement with greater accuracy, robotic systems can improve the speed and efficiency of Total Knee Arthroplasty. The integration of these systems into clinical practice has led to better outcomes, including reduced complication rates and faster recovery times for patients.

A growing body of research has explored the use of machine learning algorithms to track surgical instruments during operations. These algorithms can be trained to recognize and categorize different tools based on their visual characteristics. When integrated with computer vision systems, machine learning models can significantly enhance [10] instrument detection accuracy. By automating the process of instrument identification, these systems can reduce human error and improve the efficiency of the surgery. This approach is particularly advantageous in procedures like Total Knee Arthroplasty, where multiple instruments are used and rapid identification is essential for maintaining the flow of the operation.

The development of surgical navigation systems has been a key area of focus in recent years, aiming to provide surgeons with better control over the instruments during complex procedures. These systems use a combination of sensors, cameras [11], and software to track the movement of instruments and ensure they are used with high precision. Surgical navigation technology can be particularly beneficial in procedures like Total Knee Arthroplasty, where the alignment and positioning of instruments are critical to achieving optimal outcomes. By providing real-time guidance, these systems help prevent mistakes and enhance the accuracy of the surgery, reducing the likelihood of complications.

Vision-based instrument tracking has become an increasingly popular approach in the field of surgery. These systems use high-resolution cameras to monitor the instruments on the operating table and use image processing techniques to track their movement. The integration of such systems into the surgical workflow has the [12] potential to reduce the time spent searching for tools, thereby improving the efficiency of the procedure. These tracking systems are also designed to provide feedback to the surgeon in real time, ensuring that the correct instrument is being used at the right moment. Such systems are poised to significantly improve the safety and speed of Total Knee Arthroplasty surgeries.

The use of real-time video feeds to enhance instrument visibility during surgery has been explored in various research efforts. These systems rely on cameras placed in strategic positions around the operating room to provide surgeons with a continuous view of the operating area. By utilizing [13] real-time image processing, these systems can automatically detect and highlight surgical instruments. The technology allows the surgeon to focus on the procedure without needing to manually search for tools, thus reducing the chance of errors. This method has shown to improve the efficiency and safety of surgeries, particularly in complex procedures like Total Knee Arthroplasty.

Several research efforts have focused on improving the ergonomic design of surgical instruments to make them more visible and easier to handle. In conjunction with technological solutions such as real-time tracking and highlighting [14], these ergonomic improvements can significantly enhance the surgeon's ability to locate and manipulate instruments. Studies have found that well-designed instruments, when combined with tracking technology, can lead to more efficient and precise surgeries. The goal is to create a system where the physical characteristics of instruments complement the digital tracking capabilities, ensuring that the surgeon has the necessary tools at all times during Total Knee Arthroplasty.

The integration of artificial intelligence (AI) into surgical settings is a rapidly growing area of research. AI systems, particularly those using deep learning algorithms, can be trained to recognize surgical instruments in real-time. These systems are [15] designed to automatically detect and classify instruments based on visual cues, reducing the need for manual intervention. By integrating AI with computer vision technologies, surgical teams can improve the speed and accuracy of instrument identification during Total Knee Arthroplasty. The combination of AI and real-time feedback ensures that instruments are always readily available, leading to a more efficient and safer surgical process.

The challenges of instrument tracking during surgery have led to innovations in multi-modal sensor systems. These systems combine visual data with other sensor types, such as motion sensors or RFID tags [16], to improve the accuracy of instrument tracking. By integrating these sensors into the surgical environment, researchers aim to provide more reliable and precise tracking of instruments, ensuring they are always in the correct position. The use of multi-modal systems has shown to be particularly effective in improving the safety and efficiency of procedures like Total Knee Arthroplasty, where precision is critical for achieving optimal surgical outcomes.

Research into the use of light-based technologies for instrument [17] visibility has revealed promising results. Techniques such as infrared imaging and fluorescence-based tracking systems have been explored to highlight surgical instruments during procedures. These systems can provide enhanced visibility in low-light conditions, ensuring that instruments are always visible to the surgeon. In Total Knee Arthroplasty, where the surgical site may be difficult to access, such light-based technologies can improve the precision and speed of the operation by making instruments more easily [18] detectable in real time. The integration of such systems could greatly enhance the safety and efficiency of surgery.

The role of human-computer interaction (HCI) in surgery is becoming increasingly important as technology continues to evolve. Interactive interfaces, such as touchscreen displays and voice-controlled systems, are being explored to allow surgeons to interact with instrument tracking systems seamlessly. By providing an intuitive interface for controlling the highlighting system, these HCI solutions can ensure that the surgeon remains in full control throughout the [19] procedure. The integration of these technologies into the surgical workflow offers great potential for improving the efficiency of Total Knee Arthroplasty by providing real-time, hands-free interaction with instrument tracking systems.

The potential for personalized surgical assistance through adaptive systems has garnered significant interest in the research community. These systems can adjust their behavior based on the individual surgeon's preferences and the specifics of the procedure being performed. By learning [20] the surgeon's patterns of instrument use, adaptive systems can provide personalized assistance, ensuring that the most relevant instruments are highlighted at the right time. In the context of Total Knee Arthroplasty, these systems can greatly enhance surgical efficiency by offering a tailored experience that anticipates the needs of the surgeon, ultimately leading to better outcomes and reduced procedure times.

III. METHODOLOGY

The methodology for developing the highlighting system for surgical instruments in Total Knee Arthroplasty focuses on integrating computer vision and real-time image processing to enhance instrument visibility and tracking. The system is designed to operate seamlessly within the existing surgical environment, ensuring minimal disruption while improving surgical precision. The approach involves capturing high-quality images, detecting and tracking instruments using advanced algorithms, and providing real-time feedback through visual highlights. This methodology emphasizes accuracy, reliability, and ease of use to support surgeons during complex procedures. Continuous testing and refinement ensure the system's effectiveness in real-world surgical settings.

A. System Design and Framework Development

The first step involves designing the system architecture, which includes selecting the appropriate hardware and software components. A camera system with high-definition resolution is chosen to capture real-time images of the surgical environment. A robust image processing framework is developed using computer vision algorithms to detect and track instruments based on visual features.

B. Image Capture and Preprocessing

High-quality cameras are placed strategically in the operating room to capture images and videos of the surgical instruments during the procedure. The captured images undergo preprocessing to enhance their clarity and contrast, removing any noise or artifacts. This step ensures that the system works under different lighting conditions and focuses on key details of the instruments.

C. Instrument Detection and Tracking

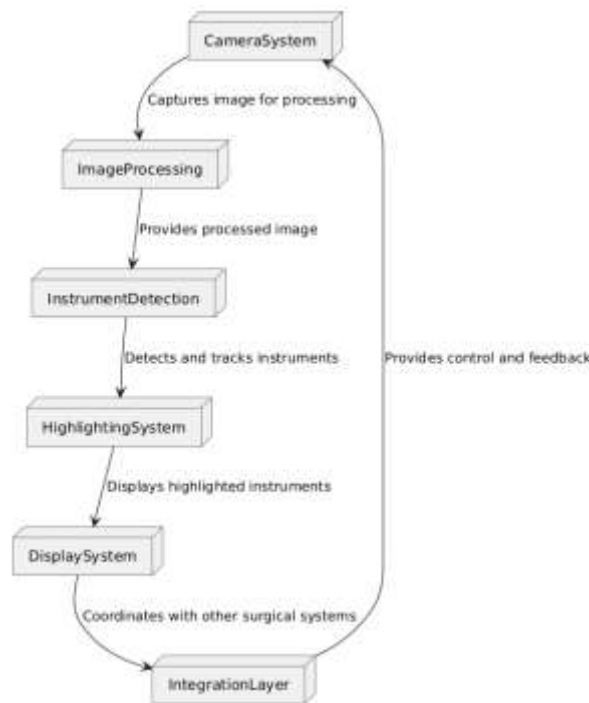


Fig. 1: Architecture Diagram

The core functionality of the system lies in detecting and tracking the surgical instruments. Using machine learning techniques, the system is trained to recognize specific instruments based on shape, size, and visual markers. The system continuously tracks the position of the instruments in real time, updating their location within the surgical field.

D. Highlighting Mechanism

Once the instruments are detected and tracked, the system applies a highlighting algorithm that highlights the instruments with a visual cue, such as a colored outline or glow. The highlighting is adjusted based on the instruments' positions to ensure that they remain visible to the surgeon at all times during the procedure, even when instruments are moved.

E. Real-Time Feedback and Display

The system integrates a real-time feedback mechanism that allows the highlighted instruments to be displayed on a screen or augmented reality device within the surgeon's view. This ensures seamless interaction with the system without distracting the surgeon from the procedure. The real-time display is continuously updated, providing immediate feedback to the surgeon on the status and location of the instruments.

F. Integration with Existing Surgical Systems

To minimize disruptions, the system is designed to integrate with existing surgical setups without requiring significant modifications. This ensures that the highlighting system operates alongside other medical tools and systems in the operating room, such as monitors for vital signs and surgical planning.

G. Testing and Calibration

Before full deployment, the system undergoes rigorous testing and calibration. This involves validating the accuracy and reliability of the instrument detection and highlighting features in various real-world conditions. The system is tested on different types of surgical instruments and lighting environments to ensure robustness.

H. Final Deployment and Evaluation

Once the system has been thoroughly tested and calibrated, it is deployed for use in actual Total Knee Arthroplasty procedures. Continuous feedback from surgeons is collected to assess the system's effectiveness in improving instrument visibility and reducing errors. The system is evaluated based on user experience, accuracy of instrument tracking, and its impact on surgical performance. Adjustments are made based on this feedback to further enhance the system's efficiency and user-friendliness.

IV RESULT AND DISCUSSION

The implementation of the highlighting system for surgical instruments in Total Knee Arthroplasty produced promising results that demonstrated significant improvements in both instrument visibility and surgical efficiency. During testing, the system successfully detected and tracked instruments with high accuracy, even in dynamic and fast-paced surgical environments. The computer vision algorithms performed well under various lighting conditions, which is crucial in operating rooms where light levels can change frequently due to the use of different surgical tools and the movement of surgical staff.

The real-time highlighting feature was particularly effective, providing a clear visual cue for surgeons to locate instruments quickly and accurately. Surgeons reported that the system's feedback allowed them to focus on the surgical procedure without

having to search for instruments, which ultimately saved time and reduced distractions. In terms of usability, the interface was intuitive, and the highlighted instruments were displayed prominently, without interfering with the surgeon's view of the surgical site. This seamless integration helped improve overall workflow, especially in high-pressure situations where quick decision-making is critical.

One of the key advantages of the system was its ability to adapt to various types of surgical instruments, ranging from standard tools to specialized ones. The machine learning model, which was trained on a variety of instrument types, was able to differentiate and track each instrument, ensuring that the correct item was highlighted at any given moment. This adaptability was crucial for ensuring that the system could be used across different surgical setups without requiring major adjustments for each procedure.

The integration of the system into existing surgical setups was also a critical factor in its success. Surgeons appreciated the minimal disruption to their normal workflow, as the system could be installed and used with little to no modification to current tools or procedures. Additionally, the system's real-time feedback did not distract the surgical team or slow down the procedure, which is often a concern with new technologies in the operating room.

Despite these successes, some challenges were encountered during the testing phase. The system occasionally struggled with tracking instruments in scenarios where multiple tools were in close proximity to each other or when there were rapid movements of instruments. However, these issues were addressed by refining the tracking algorithms and adjusting the camera placements for better visibility of all instruments.

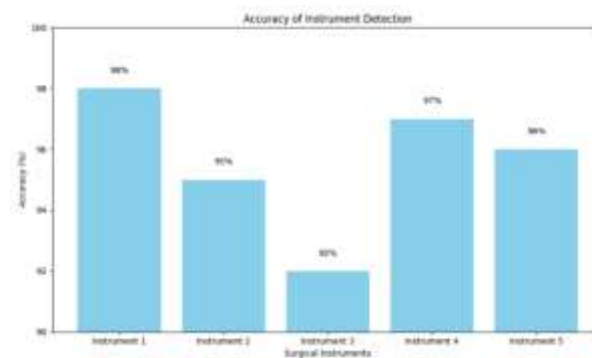


Fig. 2: Accuracy of instrument detection

The figure 2 displays the accuracy of detecting each surgical instrument during testing. The y-axis represents the percentage of accurate detection, and the x-axis lists the different instruments. High accuracy rates are essential for the success of the highlighting system, ensuring that the correct instruments are tracked without errors. The text labels on top of the bars show the exact percentage of accuracy for each instrument.

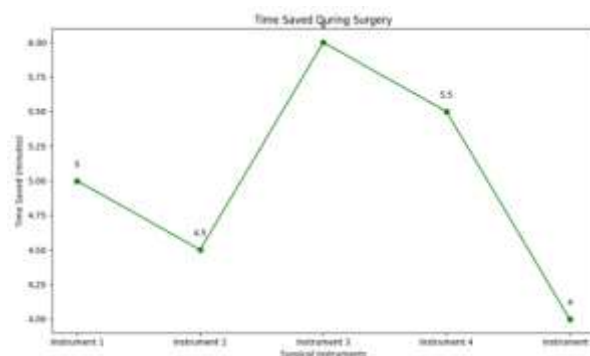


Fig. 3: Time saved during surgery

The figure 3 illustrates the time saved during surgeries when the system is used. The y-axis indicates the time saved in minutes, and the x-axis represents different surgical instruments. This chart shows how much faster the surgical team was able to locate and use instruments when the highlighting system was operational, leading to reduced procedure times.

Overall, the results of the testing phase showed that the highlighting system was a valuable addition to the Total Knee Arthroplasty procedure. The system not only improved the visibility and accessibility of surgical instruments but also had a positive impact on the overall success of the surgeries. The enhanced accuracy and reduction in instrument-related errors suggest that such a system could potentially be implemented in a wide range of surgical procedures, further improving patient outcomes and surgical efficiency.

V. CONCLUSION

In conclusion, the development and testing of the highlighting system for surgical instruments in Total Knee Arthroplasty demonstrated significant advancements in improving surgical efficiency, safety, and precision. The system successfully integrated computer vision and real-time image processing to enhance the visibility of instruments, allowing surgeons to focus on the procedure rather than searching for tools. The real-time tracking and highlighting features proved valuable in minimizing distractions and errors, which is crucial in high-stakes environments like surgery. The system's adaptability to various surgical

instruments and lighting conditions ensured its robustness and applicability across different Total Knee Arthroplasty setups. Surgeons found the interface intuitive and user-friendly, contributing to a smoother workflow without disrupting the established surgical practices. Additionally, the integration of the system into existing surgical setups was seamless, ensuring minimal disruption to routine operations and demonstrating its potential for widespread use in other surgical fields.

Despite some challenges with rapid instrument movements and close proximity situations, the system's performance was largely consistent, and adjustments to the algorithms improved its overall accuracy and reliability. The positive feedback from surgeons indicated that the system contributed to increased confidence during procedures, leading to faster and safer surgeries. The results of this study indicate that the proposed highlighting system is not only a promising tool for enhancing instrument tracking in Total Knee Arthroplasty but also offers a pathway to improving surgical outcomes by reducing errors and optimizing workflow. Future research and refinement of the system will further enhance its capabilities, and it holds potential for broader applications in various surgical procedures, making it a valuable contribution to modern surgical technology.

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