Revolutionizing Neurosurgical Guidance in Real Time with Intelligent Computer Vision

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Abstract— **Real-time neurosurgical guidance systems have the potential to revolutionize neurosurgical practice by enhancing surgical precision and safety. This paper proposes a novel intelligent computer vision (CV) pipeline for real-time neurosurgical guidance that integrates deep learning models, anatomical structure tracking, and real-time feedback. The pipeline utilizes YOLO8x(YOLO-You Only Look Once) for object detection, FPN-deeplab(FPN- Feature Pyramid Network) for tool segmentation, recurrent neural networks (RNNs) and convolutional neural networks (CNNs) for surgical phase recognition, DEEPSORT with YOLO8x for anatomy tracking, and a user-friendly GUI to present the information to surgeons. The proposed pipeline is evaluated on the MICCAI Brain Tumor Surgery Dataset (BraTS).**

Keywords: Computer Vision, Neurosurgical guidance, Real-time feedback, Object Detection, Tool segmentation, Anatomical tracking, YOLO8x

I. INTRODUCTION

Neurosurgical procedures are very intricate, and it demands exceptional precision and accuracy to minimize the danger of complications. Also, the surgical site is confined and difficult to access and it involves delicate tissues and critical structures which can be easily damaged leading to even paralysis if not handled properly. Since the field is very intricate, there are very few studies on this and the real-time cv processing in neurosurgery is challenging due to the dynamic nature of the surgical environment and the need to generate timely feedback for surgeons. Computer Vision field is promising to boost neurosurgical guidance and safety. This paper/study proposes a novel intelligent CV pipeline for real-time neurosurgical guidance aiming to address aforementioned gaps and provide surgeons with real-time, actionable information during neurosurgical procedures.

II. PROBLEM DEFINITION

Neurosurgical interventions necessitate an unprecedented level of precision, where errors bear life-threatening consequences. Traditional neurosurgical guidance heavily relies on anatomical landmarks and the expertise of the surgeon; however, these methods may prove unreliable, particularly in emergent scenarios. Consequently, misplaced catheters are not uncommon, contributing to neurological deficits. Moreover, executing procedures like external ventricular drains or ventriculostomy with precision, accuracy, and efficiency in non-immobilized patients presents a notable challenge. While neurosurgeons typically achieve a millimetre-level precision, the proposed computer vision (CV) pipeline holds the promise of delivering significantly finer-grained accuracy. Its applicability extends even to situations with historically low success rates, such as the intricate task of brain tumour removal.

III. KEY WORKS

Boping Ran [1] proposed a deep learning-based detection and counting of surgical instruments. The method uses YOLOv7x object detection algorithm to count the number of surgical instruments. Isabella Chiurillo [2] proposed a novel device, Zeta Cranial Navigation System which uses Snap-Surface and Real Track algorithm for real-time tracking without cranial fixation, fiducials, or other markers. Y.Wang et al.[4] proposed real-time detection of surgical instruments based on YOLOv4 and YOLOv5 models to assist surgeons in minimally invasive surgery. Mohammad Havaei [3] proposed a novel CNN architecture for brain tumour segmentation.

IV. EVALUATION CRITERIA

The MICCAI Brain Tumour Surgery Dataset (BraTS) is utilized for evaluation, containing annotated brain tumour surgery videos with tumour segmentations, brain structures, and surgical tools. Evaluation metrics include Intersection over Union (IoU), Precision, Recall, Latency, F1 score, and Patient Outcomes.

V. PROPOSED METHOD

The intricate realm of neurosurgery demands exceptional precision and accuracy, where human perception and expertise can face challenges in dynamic operating theatre.

1. Image Acquisition and Preprocessing: The pipeline relies on the acquisition and preprocessing of surgical video feeds at 30 fps, capturing intricate movements of surgical tools and anatomical structures in real time. Preprocessing includes filtering, colour correction, and frame interpolation for smooth motion.
2. Object Detection: YOLO8x (You Only Look Once), a state-of-the-art object detection algorithm is used here. Its ability to process images at 750 frames per second surpassing the frame rate of surgical video feeds makes it a suitable choice for real-time neurosurgical guidance. YOLO8x excels at identifying and recognizing surgical tools, neuroanatomical structures, and other objects within the surgical field even in poorly lit environments.
3. Tool Segmentation: Once the object is detected, surgical tools need further refinement using semantic segmentation model. The proposed CV pipeline employs a semantic segmentation model, FPN-deeplabv3+(FPN-Feature Pyramid Network) as it simultaneously detects and segments surgical tools within the surgical field providing a more integrated view of the surgical environment. FPN-deeplab's ability to extract precise boundaries of surgical tools enables surgeons to gain detailed information about shape, orientation and position leading to more informed surgical decisions.
4. Surgical Phase Recognition: The pipeline utilizes a cascaded architecture that combines the strengths of recurrent neural networks (RNNs), temporal convolutional networks (TCNs), and convolutional neural networks (CNNs) to capture both temporal and

spatial information. RNNs excel at modelling long-range temporal dependencies, effectively capturing the sequential nature of surgical procedures. TCNs, on the other hand, are well-suited for extracting high-level features from surgical videos, providing the model with a deeper understanding of the surgical context. Meanwhile, CNNs excel at processing spatial information and identifying patterns in the arrangement of surgical tools and anatomical structures. By combining these three models, the proposed pipeline can achieve more accurate surgical phase recognition.

5. Anatomy Tracking: Tracking anatomical structures throughout the surgical procedure provides valuable insights into the progression of the surgery and potential areas of concern. To enhance the accuracy and robustness of the tracking process, the proposed pipeline integrates DEEPSORT with YOLO8x, a combination that leverages the strengths of both algorithms. YOLO8x excels at object detection, providing initial detections and embedding vectors for each object. DEEPSORT then utilizes the embedding vectors to establish track associations, update state estimates, and manage tracked objects, effectively tracking anatomical structures in real time. This integration enables the CV pipeline to effectively track anatomical structures in challenging conditions such as occlusions and cluttered environments.

6. Real Time Feedback: By seamlessly integrating and presenting this information through a user-friendly GUI, the proposed CV pipeline empowers surgeons to make informed decisions, maintain precision, and enhance the overall efficiency and safety of their procedures.

A. Equations

$$P(\%) = TP / (TP + FP) * 100 \tag{1}$$

$$R(\%) = TP / (TP + FN) * 100 \tag{2}$$

$$F1(\%) = 2PR / (P + R) * 100 \tag{3}$$

$$AP = \int_0^1 P dr \tag{4}$$

(1) Precision is the proportion of positive objects that are correctly classified as positive. (2) Recall is the proportion of positive objects that are detected by YOLO8x. (3) F1 score is a weighted average of precision and recall. (4) Mean average precision is a more comprehensive metric that considers the precision and recall for each object class.

VI. DISCUSSION

To address the need for enhancing surgical precision and safety in intricate neurosurgical procedures, the proposed CV pipeline for real-time neurosurgical guidance effectively integrates deep learning models, anatomical structure tracking, and real-time feedback. It processes surgical video feeds at a frame rate of 30 fps to provide real-time feedback to surgeons, allowing them to make informed decisions and maintain precision throughout the procedure. The pipeline employs YOLO8x, FPN-deeplabv3+, RNNs, and CNNs to extract valuable information from surgical video feeds. YOLO8x excels at object detection, while FPN-deeplab precisely segments surgical tools. RNNs and CNNs effectively recognize the surgical phase, enabling surgeons to navigate the surgical phases smoothly. DEEPSORT with YOLO8x tracks anatomical structures accurately, even in challenging conditions. Moreover, tracking anatomical structures, such as the tumour and surrounding brain tissue, provides surgeons with insights into the progression of the surgery and potential areas of concern. This information can guide surgical actions and minimize risks to delicate tissues. To seamlessly present the extracted information to surgeons in a clear and accessible manner, the pipeline integrates a user-friendly GUI.

A. Figures and tables

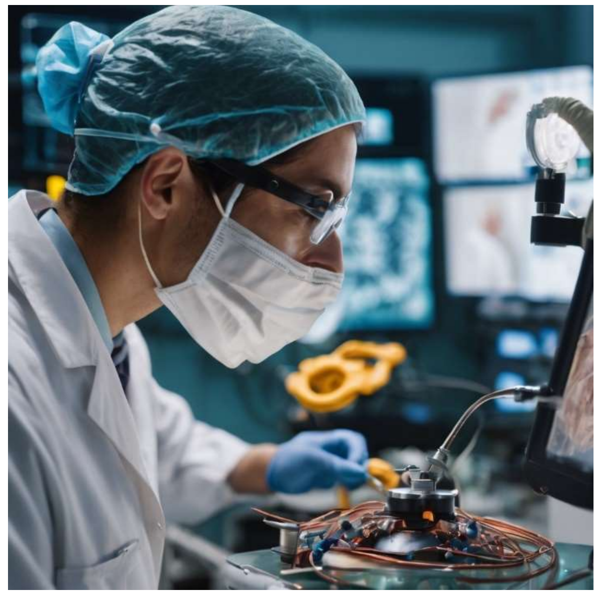

Fig. 1. Generative image of a neurosurgeon using cv pipeline for guidance in real-time

VII. CONCLUSION

The proposed CV pipeline for real-time neurosurgical guidance demonstrates the potential of computer vision to enhance surgical precision and safety. This innovative approach holds promise for revolutionizing neurosurgical practice and improving patient outcomes.

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