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GUI-Based Framework for Automated Deep Learning Synthetic CT Generation and Contouring for Canine Adaptive Radiotherapy on a Dual-Robot Radiotherapy System

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ABSTRACT

KOALA (Kilovoltage Optimized for AcceLerator Adaptive Therapy) is a low-cost adaptive radiotherapy system designed for resource-limited settings. However, cone-beam CT (CBCT) images acquired using the KOALA system are affected by scatter artifacts and inaccurate Hounsfield Unit (HU) values, limiting their use for accurate dose calculation and treatment planning. To address these challenges, we developed a GUI-based framework integrating deep learning-based synthetic CT (sCT) generation and automated contouring into a single workflow for canine adaptive radiotherapy.

A PySide6-based GUI was developed to support DICOM loading, orientation correction, synchronized multi-planar visualization, contour editing, and DICOM RTSTRUCT export. A 3D U-Net architecture was developed for CBCT-to-sCT conversion, while an nnU-Net model was trained for automated segmentation of the planning target volume (PTV), body contour, and organs-at-risk (OARs).

The framework enabled end-to-end CBCT processing with minimal user intervention while maintaining interactive review verification. The segmentation model achieved a mean Average Precision (mAP@0.5) of 0.89, while the sCT generation model achieved a peak Structural Similarity Index Measure (SSIM) of approximately 0.88, demonstrating preservation of anatomical detail and tissue contrast. The framework generated planning-ready datasets compatible with the KOALA treatment planning workflow.

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INTRODUCTION

Adaptive radiotherapy relies on accurate anatomical imaging and target delineation to support treatment adaptation and dose calculation. While CBCT provides on-board imaging for adaptive workflows, image artifacts and inaccurate HU values limit its use for treatment planning. In addition, manual delineation of targets and OARs remains labor-intensive and can increase clinical workload. These challenges motivate the development of automated tools to improve the efficiency and accuracy of CBCT-based radiotherapy workflows.

METHODS AND MATERIALS

A GUI-based framework was developed using PySide6 to support CBCT-based adaptive radiotherapy workflows for the KOALA system. The framework enables DICOM loading with orientation correction, synchronized multi-planar visualization, adjustable window/level controls, contour editing tools, and automated export of DICOM RTSTRUCT files.

For sCT generation, a 3D U-Net deep learning architecture was developed to convert canine CBCT images into planning-quality sCT images.

For automated contouring, an nnU-Net segmentation model was trained to delineate the PTV, body contour, and OARs. The model was trained on 28 canine patient cases, split into 80% for training, 10% for validation, and 10% for testing.

As shown in Figure 1, the sCT images and generated contours were integrated into the GUI for interactive review, verification, and editing prior to export to the treatment planning system.

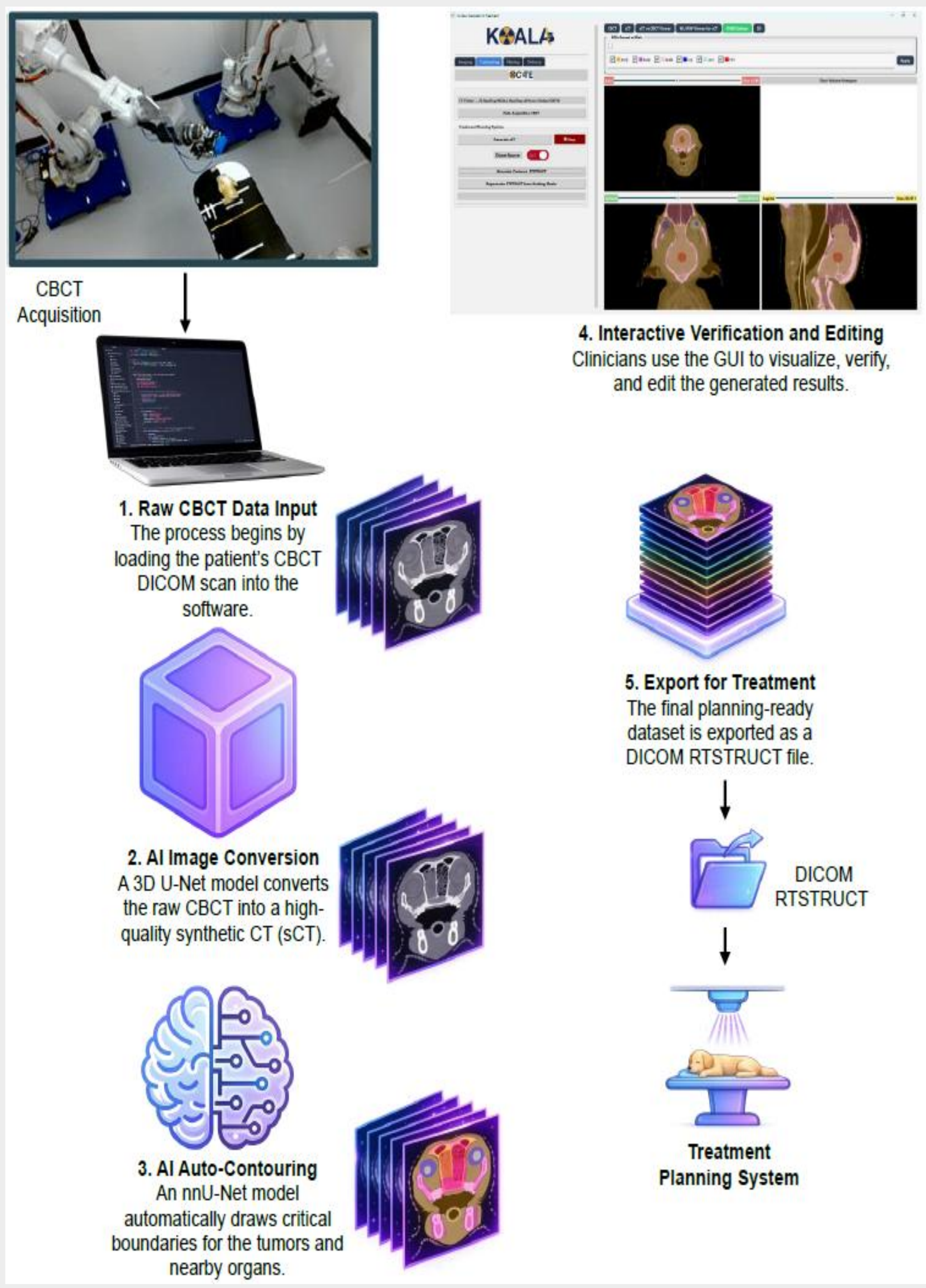

Figure 1. KOALA GUI-based CBCT treatment planning workflow.

RESULTS

The developed framework enabled end-to-end canine CBCT processing with minimal user intervention while maintaining interactive visual verification. The automated contouring model demonstrated reliable segmentation performance, achieving a mean Average Precision (mAP@0.5) of 0.89, as shown in Figure 2. Representative segmentation examples in Figure 3 demonstrated accurate delineation of tumors and OARs in canine osteosarcoma and glioma cases.

The sCT generation model achieved a peak SSIM of approximately 0.88, as shown in Figure 4, demonstrating improved preservation of anatomical structures and tissue contrast relative to the original CBCT images. Representative examples from a canine nasal tumor case are shown in Figure 5, illustrating enhanced soft-tissue visualization and improved anatomical fidelity in the generated sCT images.

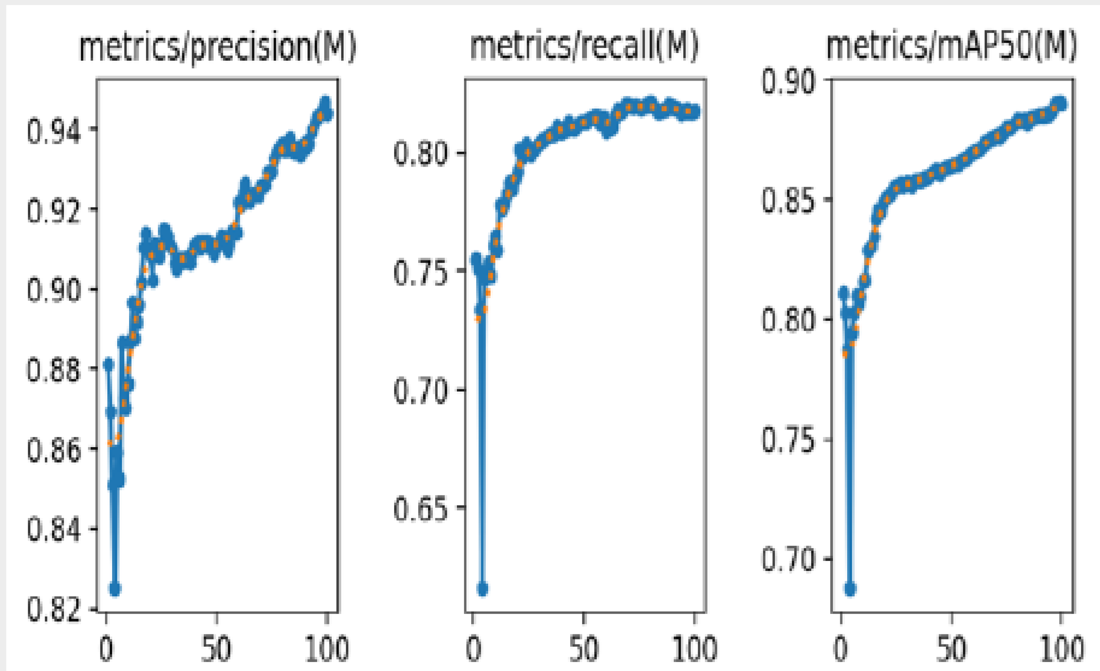

Figure 2. Validation precision, recall, and mAP curves demonstrating progressive improvement in automated contouring performance across training epochs.

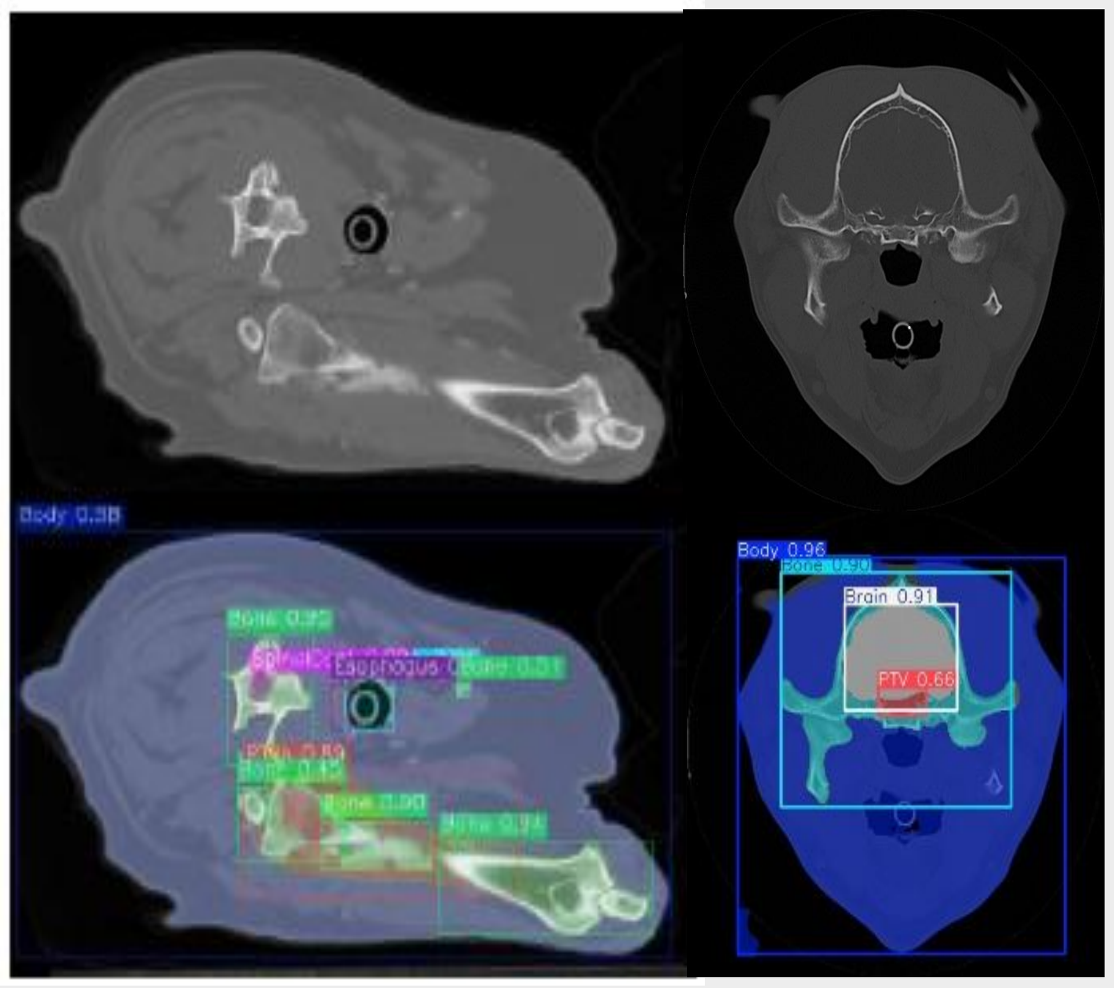

Figure 3. Representative automated segmentation results showing accurate delineation of the PTV and OARs in canine osteosarcoma and glioma cases.

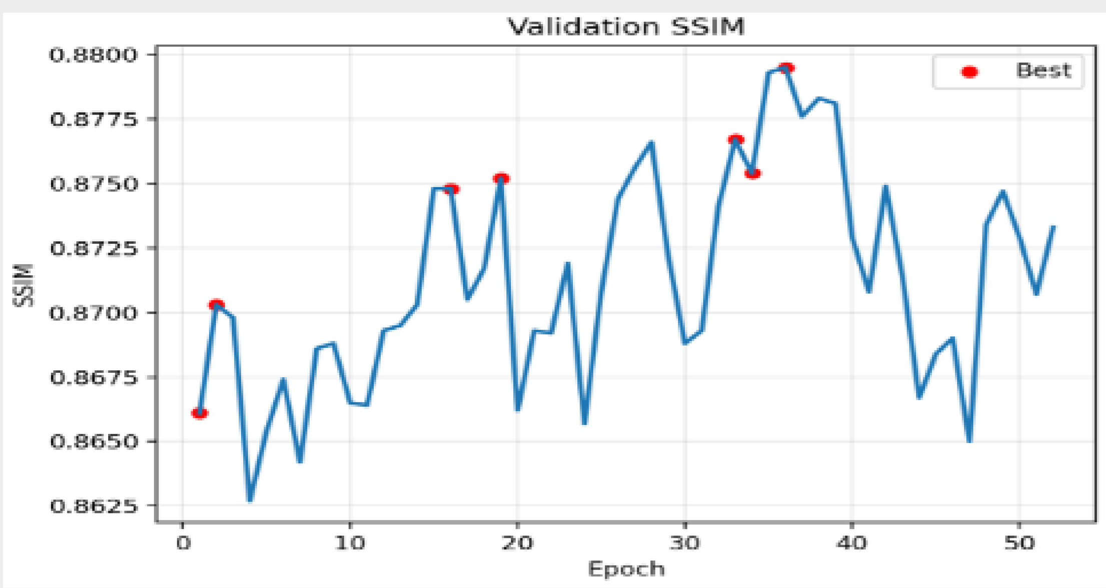

Figure 4. Validation SSIM curve demonstrating improved sCT image quality.

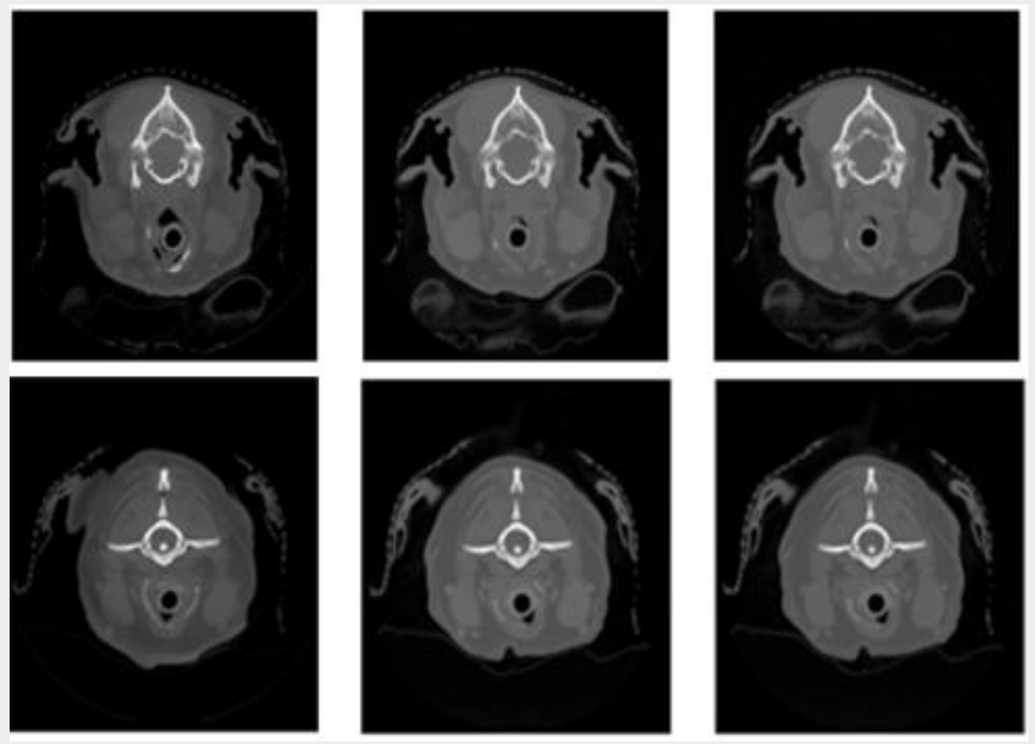

Figure 5. Visual comparison between CBCT, generated sCT, and reference CT images showing improved anatomical detail.

DISCUSSION

This work demonstrates the feasibility of integrating deep learning-based sCT generation and automated contouring into a unified GUI workflow for canine adaptive radiotherapy. The framework simplifies CBCT-based treatment planning by combining image conversion, segmentation, visualization, editing, and RTSTRUCT generation within a single interactive platform.

The automated contouring model reduced the need for extensive manual delineation while maintaining strong segmentation performance. Similarly, the sCT generation model improved image quality and anatomical consistency compared with raw CBCT data, supporting more reliable dose calculation. These capabilities are particularly valuable in low-resource radiotherapy environments where streamlined workflows and reduced planning time are essential.

CONCLUSIONS

A GUI-based framework integrating CBCT-to-sCT conversion and deep learning auto-contouring was successfully developed for the KOALA adaptive radiotherapy system. The framework demonstrated reliable segmentation accuracy and high-quality sCT generation while enabling export of planning-ready dataset through an interactive user interface.

By combining advanced deep learning techniques with an accessible GUI workflow, the framework addresses key limitations of CBCT-based treatment planning and supports the development of efficient adaptive radiotherapy solutions for resource-limited environments.

REFERENCES

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