MIRAGE: Multi-modal Image-guided Robotic Assistant for Generalized IGRT – Enhancing Precision Localization and Treatment Efficiency

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Aim: This project aims to design, develop, and evaluate MIRAGE, an expansion device for CT treatment beds designed to enhance clinical workflow efficiency and target localization accuracy. MIRAGE allows auxiliary equipment (e.g., ultrasound probes, visible imaging systems, patient immobilization devices, etc.) to be seamlessly integrated into existing CT systems.

Materials and Methods: The MIRAGE control platform is constructed with Xiaomi Cybergear motors and FUYU linear guide rails. The system uses the STM32F4 chip as the main controller and 3D-printed components are used to build a mobile platform with five degrees of freedom, which can be operated along the patient's body surface. The support structure is mainly made of CNC-machined aluminum alloy, which ensures a lightweight frame and sufficient rigidity. The rail design can reduce the operating space and increase the load capacity compared to traditional robotic arms. The stepper motors on the linear rail are driven by ZDT controllers and supplemented by magnetic encoders for FOC closed-loop control. On the software side, the system runs on the FreeRTOS for real-time scheduling, reducing latency and increasing scalability, while data transmission is secured by an encrypted CAN bus protocol.

Results: The prototype features five axes of motion, sub-centimeter positioning accuracy, and an end-effector loading capacity of 1.5 kg. By integrating the ultrasound probe and the visible imaging system into the frame, physicians can simultaneously acquire CT, ultrasound, and visible images during treatment, allowing for real-time monitoring and precise correction of small deviations in patient position.

Conclusion: We have successfully built a prototype of the MIRAGE system. This not only ensures that the radiation beam is precisely directed to the target area, effectively reducing radiation exposure to surrounding normal tissues but also reduces positioning and correction time and improves the efficiency of the treatment process and patient experience.