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碩士論文

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Master's Thesis



主動式眼球手術仿體系統開發

Development of a Dynamic Eye Phantom

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摘要

本研究旨在開發一套主動式眼球手術仿體系統，以模擬真實眼科手術環境，評估眼科手術機器人的手術表現。仿體系統包含鞏膜仿體、仿生眼球機構及三軸並聯式可動平台三大部分。鞏膜仿體以 PDMS 材料製作，具備與人體鞏膜相近的彈性特性，並透過三自由度旋轉機構與扭力彈簧模擬眼球於手術器械作用下的生理旋轉運動，且透過編碼器記錄旋轉角度以量化施術表現。可動平台則採用 Tripod 並聯式機構設計，透過線性馬達驅動，實現兩個旋轉自由度與一平移自由度，以模擬眼球於手術期間的自主運動。透過引入頻譜分析改善數據驅動迭代學習控制的學習濾波器設計，平台能有效追蹤生理運動軌跡。實驗結果驗證了此控制方法實踐於眼球仿體可動平台之可行性，而鞏膜仿體與仿生眼球機構則重現了眼球組織的物力特性，並具備紀錄數據的功能。

關鍵字：眼球仿體、三腳架並聯機構、迭代學習控制、頻譜分析



Abstract

This research aims to develop an dynamic eye phantom to simulate a realistic ophthalmic surgical environment and evaluate the performance of ophthalmic surgical robots. The phantom system consists of three primary components: a scleral phantom, a biomimetic eyeball mechanism and a three-axis parallel moving platform. The scleral phantom is made of PDMS material, exhibiting elastic characteristics similar to human sclera. It employs a three-degree-of-freedom rotational mechanism coupled with torsion springs to mimic physiological rotational movements of the eyeball induced by surgical instruments. Encoders record rotational angles to quantify surgical performance. The moving platform adopts a tripod parallel mechanism driven by linear motors, providing two rotational degrees of freedom and one translational degree of freedom, simulating the physiological movements of the eyeball during surgery. By employing spectral analysis (SA), which improves the learned data-driven inversion, the platform effectively tracks physiological mo-

tion trajectories. Experimental results demonstrate the feasibility of applying this control method to the phantom's moving platform. Meanwhile, the scleral phantom and biomimetic eyeball mechanism successfully replicate the physical characteristics of ocular tissues and possess data recording capabilities.

Keywords: Eye phantom, Tripod mechanism, Iterative learning control, Spectral analysis