Southern Taiwan University of Science and Technology

Graduate School of Electrical Engineering

Ph.D. Dissertation

FPGA Realization of Forward Kinematics and Inverse Kinematics for Five-Axis Articulated Robot Arm

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Abstract

This dissertation presents a study of the forward and inverse kinematics for a five-axis articulated robot arm based on Field Programmable Gate Array (FPGA) technology. Some trigonometric functions using Look-Up Table (LUT) and Taylor series method are used in hardware implementation to speed up of tracking the motion trajectoriesapplied for forward kinematics and invers kinematics for five-axis articulated robot arm. Firstly, the forward kinematics and inverse kinematics of five-axis articulated robot arm are derived. Secondly, the computations algorithms and its hardware implementation are described. Thirdly, Very high speed integrated circuits Hardware Description Language (VHDL) is applied to describe the overall hardware behavior of forward and inverse kinematics. Additionally, Finite State Machine (FSM) is applied for reducing the hardware resource usage. Further, to verify the correctness of the forward and inverse kinematics for five-axis articulated robot arm, a co-simulation work is constructed by Modelsim and Matlab Simulink. The forward and inverse kinematics hardware is run by Modelsim and a test bench which generates stimulus to Modelsim and displays the output response that is taken in Simulink. Under this design, the combination of the forward and inverse kinematics simulation for tracking the motion trajectories is adopted. Fourthly, the design of forward and inverse kinematics IPs for five-axis robot arm is implemented by a single FPGA. Additionally, a Nios II processor can be embedded into FPGA to construct a System on a Programmable Chip (SoPC) developing environment. Programs in Nios II processor are coded in C language and IPs digital hardware is described by VHDL. The Man-Machine Interface (MMI) developed by Visual Basic language which displays the results of computations kinematics in FPGA into decimal number for easy checking the correctness of results. Therefore, the digital hardware/software co-design based on the SoPCis suitable for the development of the forward and inverse kinematics for five-axis articulated robot arm. Finally, an experiment system has been built up as well as some experimental results have been demonstrated to verify the effectiveness and correctness of computations for forward and inverse kinematic which is applied to the real five-axis articulated robot arm.

摘要

本文基於 FPGA（現場可程式邏輯閘陣列）技術提出了前向和逆向運動學的五軸模組化機械臂之研究。首先，推導五軸關節型機械手臂的前向運動學和逆向運動學。其次，針對演算法和硬體實現進行了描述。第三，超高速積體電路硬體描述語言（VHDL）被用於描述前向和反向運動學的整體硬體行為。此外，運用有限狀態機器（FSM）以減少硬體資源的使用。為了驗證五軸關節型機械手臂的前向和逆向運動學的正確性，將結合 Modelsim 和 Matlab Simulink 進行模擬。前向和逆向運動學的硬體是由 Modelsim 執行，而 Modelsim 測試平台產生的輸入訊號及輸出響應將顯示在 Simulink 中。根據這樣的設計，前向及逆向運動學及運動軌跡追蹤可以在數微秒內完成。第四，五軸機械臂的前向和逆向運動學 IP 設計將由單顆 FPGA 實現。此外，Nios II 處理器可以嵌入到 FPGA 中以建構 SoPC（在系統可編程片）開發環境。在 Nios II 處理器的應用程式以 C 語言撰寫，而 VHDL 將用於描述前向和逆向運動學的數位硬體電路。另外，本論文也利用 visual basic 開發一套人機介面(MMI)，此將呈現前向和逆向運動學 IP 計算後的結果。因此，基於所述，SoPC 將適合發展五軸機械手臂的前向和逆向運動學的硬體/軟體共同設計環境。最後，將建立一個實驗系統並有實驗結果來證實應用於五軸模組化機械手臂的前向及逆向運動學計算的有效性和正確性。

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