國　立　清　華　大　學

碩士論文

透過 CMOS-MEMS 實現單晶整合觸覺/近接感測器之感測性能提升

The Tactile Force/Proximity Sensors Achieving Performance Enhancement Through CMOS-MEMS Monolithic Integration

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摘要

隨著工業 5.0 以及物聯網的盛行發展，現今人工智慧機器人為求精準的物品夾取，通常會將觸覺感測器整合視覺感測器，但仍然可能會產生無法判讀極近的距離或視覺死角的問題存在。因此本研究希望透過 TSMC CMOS 標準製程平台，單晶整合壓阻式觸覺力感測器和電容式近接感測器，期望能擁有在極近距離下的非接觸感測之訊號讀取，並同時提升此兩種感測器之性能提升，實現更精確的物體抓取和控制。電容式近接感測器性能提升的部分，利用浮動電位之金屬背板，讓近接感測器之訊號響應度提升，並且設計全對稱式陣列指叉電容結構降低近接感測器之電場耦合，達到電場分布最佳化以提升感測靈敏度；壓阻式觸覺力感測器性能提升的部分，利用自體受力結構設計，當結構受予正向力時，橋狀結構兩側會產生反向應力集中，並用惠斯通全橋的電路整合使感測靈敏度提升，同時也利用差分電路特性，將材料本身之熱飄移訊號消除。在後製程以及電性量測驗證，證明結構設計所帶來之性能提升外，也會能夠針對環境訊號補償，提升訊號精度的同時，也說明本研究設計有達到預期之效果。

關鍵字：CMOS-MEMS、單晶整合、觸覺力感測器、指叉電容近接感測器、反向應力、浮動背板、電場耦合、惠斯通全橋、熱飄移

Abstract

With the evolution of Industry 5.0 and the Internet of Things, AI robots often integrate visual sensors with tactile sensors for precise object manipulation. However, issues such as the inability to detect objects at very close distances and visual blind spots persist. This study demonstrates the tactile force sensor integrated with the proximity sensor using the TSMC CMOS process, both achieving performance enhancement and mitigating drift caused by environmental coupling. For the capacitive proximity sensor, floating shielding electrodes improve the proximity sensor's responsiveness, and symmetric structure design of proximity sensor has reduced the electric field coupling, thereby optimizing field distribution and sensitivity. For the piezoresistive force sensor, with a guided-beam structure and Wheatstone full-bridge routing when under a normal force, boosts the signal sensitivity and eliminates the thermal drift through differential signal processing.

Keywords: CMOS-MEMS, monolithic integration, tactile force sensor, proximity sensor, reverse stress, floating shielding electrode, electric field coupling, Wheatstone full-bridge, thermal drift.