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應用於心理壓力監測之具備整合式無線收發器與電源管理的多模態生物感測系統晶片

A Multimodal Biosensing System-on-Chip with Integrated Wireless Transceiver and Power Management for Stress Monitoring



隊伍名稱｜老師說的都隊 The Teacher Is Always Right

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美國華盛頓大學電機工程博士，現任陽明交通大學電機工程學系教授，長期投入低功耗積體電路、無線感測系統與生醫電子晶片之研究，並具備豐富的積體電路設計、系統整合與跨領域研究經驗。

研究領域

低功率積體電路設計、射頻通訊積體電路、感測器介面電路、能量擷取與管理電路設計。

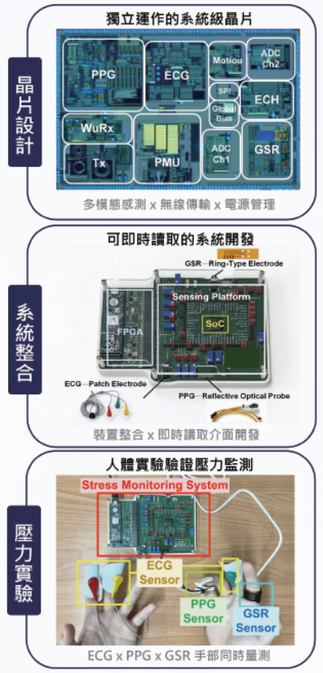
作品摘要

本作品提出一套應用於心理壓力監測之全整合式多模態生物感測系統晶片，旨在解決現有穿戴式壓力監測裝置過度依賴單一生理訊號、系統整合度不足，以及長時間配戴時功耗受限等問題。壓力狀態涉及心血管變化、汗腺活動與化學訊號等多重生理機制，若僅以光電容積描記訊號推估心率變異度，容易受到運動偽影、環境光與個體差異影響，難以完整反映使用者的身心狀態。因此，本系統整合心電圖、電化學感測、皮膚電反應與光電容積描記四種感測模態，期望透過多種生理資訊提升壓力監測的準確性與可靠度。

在系統架構上，本作品將多模態感測前端、無線收發器、電源管理電路與後端讀取平台整合於單一系統中。ECG與ECH讀取電路採用電路共享技術，共用電流平衡儀表放大器作為前端，不僅可降低功耗與晶片面積，也能維持高共模抑制能力與低雜訊表現。GSR讀取電路則設計自動輸入範圍調整機制，可因應不同使用者與接觸條件下的大範圍皮膚阻抗變化，避免前端電路飽和，提升長期與短期壓力訊號的量測穩定性。PPG讀取電路結合環境光補償、動態範圍提升與改良式預充電技術，以降低光電二極體寄生電容造成的電荷共享問題，進一步提升訊號品質。

此外，本晶片整合喚醒式無線接收器與基於ADPLL的無線發射器，可在低功耗待機狀態下接收喚醒訊號；電源管理電路則透過自適應增益與頻寬控制，在輕載與重載切換時維持穩定供電。後端讀取系統能即時接收並顯示ECG、PPG、GSR等訊號，並進一步計算心率、脈搏到達時間與壓力變化結果，讓使用者能直觀掌握自身生理狀態。

本作品展現高度整合、低功耗、即時監測與多模態分析的特色，未來可應用於智慧醫療穿戴裝置、居家健康照護與個人化壓力管理平台，作為日常化、連續化壓力監測系統的重要核心技術。



圖一 作品設計與架構圖。

Abstract

This work presents an integrated multimodal biosensing system-on-chip for psychological stress monitoring. Existing wearable stress monitoring devices often rely on a single physiological signal, have limited system-level integration, and are not sufficiently power-efficient for long-term use. Since psychological stress involves cardiovascular activity, sweat gland response, and biochemical variations, stress evaluation based only on PPG-derived heart rate variability may be unreliable in daily-life scenarios, where PPG signals are affected by motion artifacts, ambient light, skin contact conditions, and individual differences. To achieve comprehensive and robust stress assessment, this work integrates electrocardiography (ECG), electrochemical sensing (ECH), galvanic skin response (GSR), and photoplethysmography (PPG) into a single biosensing platform.

The proposed system consists of sensing front-ends, wireless transceivers, a power management unit, and a backend readout platform. The ECG and ECH readout circuits adopt a circuit-sharing technique, where a current-balancing instrumentation amplifier is shared as the analog front-end. ECG is acquired as a differential voltage signal, while ECH is processed through a common-mode sensing path. By sharing the same front-end, both chip area and power consumption can be reduced. The current-balancing instrumentation amplifier also provides high common-mode rejection and low-noise performance, essential for weak biopotential signal acquisition.

The GSR readout circuit monitors skin conductance variations related to sweat gland activity. Because skin impedance varies significantly among users and electrode contact conditions, the circuit may suffer from saturation under large input current variations. To address this issue, an automatic input range adjustment mechanism is implemented to maintain stable operation over a wide impedance range. Therefore, both slow-varying skin conductance level and fast-varying skin conductance response can be measured for stress analysis.

The PPG readout circuit acquires optical signals related to blood volume changes. To overcome the small AC component, large DC offset, ambient light interference, and photodiode parasitic capacitance, the circuit incorporates ambient light compensation, dynamic range enhancement, and an improved pre-charging technique. The pre-charging method reduces charge-sharing effects, prevents signal distortion, and improves sensing stability, enabling reliable extraction of heart rate and pulse arrival time.

For wireless and power-efficient operation, the system integrates a wake-up receiver, an ADPLL-based transmitter, and an adaptive power management circuit. The wake-up receiver allows low-power standby operation and activates sensing modules only when needed, while the transmitter supports wireless data transmission without external communication components. The power management circuit uses adaptive gain and bandwidth control to maintain stable supply voltage during workload transitions. Finally, a backend readout platform displays real-time ECG, PPG, and GSR signals and extracts stress-related physiological indicators. Overall, this work demonstrates a highly integrated, low-power, real-time multimodal biosensing SoC with strong potential for wearable healthcare and personalized stress management applications.

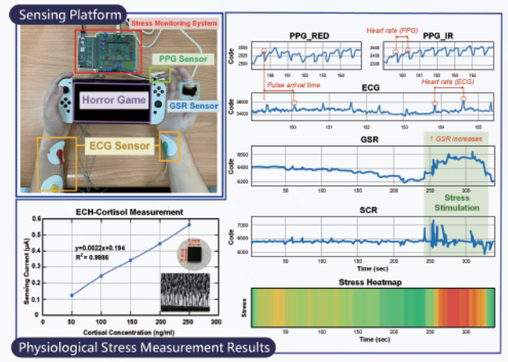


Fig. 2 Integrated multimodal sensing platform and measured biosignals.