Doctoral Dissertation
Doctoral Program in Electrical, Electronics and Communications Engineering
(36th cycle)

Design of Pulse Wave Velocity and Blood Pressure Devices for Cardiovascular Health Evaluation

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Summary

Cardiovascular diseases are the leading cause of death worldwide, making the regular monitoring of critical biomarkers like blood pressure and pulse wave velocity (PWV) essential for prevention. This thesis explores new methodologies and hardware/firmware solutions to enhance the accuracy, convenience, and reliability of non-invasive cardiovascular health monitoring systems. The thesis begins with an overview of the motivation, problem statement, objectives, novelty, and research contributions, emphasizing the critical need for precise and accessible cardiovascular health monitoring. A comprehensive literature review follows, covering the physiological background of the cardiovascular system, including the heart, blood vessels, and blood pressure. It examines biosignals analyzed in this research, such as arterial pulse and photoplethysmogram signals, and provides an overview of both invasive and non-invasive methods for assessing PWV and blood pressure (BP). The review highlights the limitations of existing technologies, establishing the context for the advancements proposed.

This thesis addresses key issues in PWV study from hardware, firmware, and software perspectives. It presents the analysis and application of commercial micro force sensors for PWV assessment, detailing operational principles, calibration processes, and experimental setups. Preliminary results form the foundation for developing the PWV acquisition system. A novel wireless system for real-time PWV assessment is introduced, featuring pen-shaped probes using Bluetooth Low Energy protocol for wireless communication. These custom-designed probes include a printed circuit board, a rechargeable battery, and a piezoresistive load cell, enabling efficient data collection and real-time data transmission to a graphical user interface.

Validation against the gold-standard SphygmoCor device demonstrated a strong linear correlation and reliable PWV estimation. The system, designed for clinical usability, includes user-friendly features and a synchronized acquisition process, reducing complexity for clinical personnel and meeting medical safety standards. The thesis also examines the variability and potential inaccuracies in traditional PWV evaluation methods, specifically fiduciary points. A novel region-based cross-correlation (RBCC) method is proposed, using signals with consistent shapes for cross-correlation, ensuring constant portions of the signal for PWV calculation

across different sites. The RBCC method showed high accuracy and robustness to noise compared to the intersecting tangent method, validated with data from 75 healthy participants. Research on cuffless BP monitoring was conducted in collaboration with the Wireless Sensors Network Group at Tyndall National Institute, University College Cork. This included developing a custom device for real-time pulse transit time measurement, focusing on the elbow and thumb. A personalized model for detecting blood pressure variations due to physical or cognitive workload was also developed, using data from the custom device to monitor changes accurately. The study highlights the importance of personalized approaches in improving machine learning model predictions for health monitoring.
Additionally, motion artifacts in PPG data were detected using the *catch22* feature subset and anomaly detection algorithms. Personalized models significantly enhanced motion artifact detection performance compared to generalized models, aligning with broader healthcare trends. Key findings of this thesis include the development of a cost-effective, user-friendly device for PWV measurement, robust algorithms for PWV assessment, advancements in non-invasive BP monitoring, and improved long-term monitoring reliability. These contributions represent significant improvements in non-invasive cardiovascular health monitoring, making it more accessible and practical for widespread clinical use.