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Ph.D. DISSERTATION DEFENSE

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Title: Cardiovascular System Monitoring Using Wearable Sensors

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ABSTRACT

The objective of this dissertation is to introduce the utilization of wearable sensors to observe the cardiovascular system in individuals with cardiovascular complications and fetuses. The section of the dissertation reviews the clinical significance of hemodynamic monitoring, cardiovascular disease detection, and continuous fetal heart rate estimation, as well as the current monitoring techniques and their limitations.

This dissertation discusses the limitations of current methods for detecting valvular heart disease (VHD) and peripheral artery disease (PAD), and introduces wearable-based methodology to address the limitations. For this purpose, inertial measurement units (IMU) including seismo-cardiogram (SCG), gyro-cardiogram (GCG), and accelerometer contact microphone (ACM) were utilized in combination with machine learning (ML) and deep learning (DL) techniques to identify abnormal patterns corresponding to conditions in central and peripheral arteries. Furthermore, this dissertation introduces a novel methodology based on strain sensors for cuffless estimation of blood pressure at the fingertip. The method proposes a novel feature extraction method to estimate systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) from the pulse signals acquired by a strain plethysmography (SPG) sensor.

The following section of the dissertation investigates the detection of abnormality in left ventricular ejection fraction (LVEF) and mean pressure gradient (MPG) by fusing information from biopotential and vibrational recordings on the chest wall. The LVEF abnormality detection involves the estimation of pre-ejection period (PEP) and left ventricular ejection time (LVET), and finding its relevance to abnormal LVEF values. Another study on MPG stratification motivates the use of low-cost wearable sensors to categorize AS patients into mild, moderate, and severe. The proposed framework leverages the time intervals of the vibrational signals to classify the AS severity with high accuracy. The dissertation also presents novel strategies for augmenting plethysmography methods for hemodynamic monitoring. To this end, the use of

micro-electromechanical systems (MEMS) strain sensors is proposed and investigated for estimating hemodynamic parameters such as heart rate variability (HRV), at the radial (on the wrist) and digital (on the finger) arteries.

Finally, the dissertation presents a novel framework that combines FECG and inertial sensors to monitor fetal heart rate (FHR). This approach employs an EMD-based signal refinement and two sensor fusion methods to estimate FHR. Additionally, a signal-to-signal translation technique based on a generative adversarial network (GAN) is introduced to cancel fetal movement in abdominal ECG recordings. The dissertation also presents the dual-path source separation (DPSS) method for fetal ECG extraction. This method solves an under-determined problem by separating fetal and maternal ECG signals from a single-channel abdominal ECG recording. The proposed framework and techniques contribute to more accurate and reliable fetal monitoring.

The dissertation has made a significant contribution to the expanding field of research on wearable sensors for cardiovascular monitoring. The findings offer valuable insights into the potential advantages and obstacles related to the utilization of wearable sensors for cardiovascular monitoring and fetal heart rate extraction. It is evident that wearable sensors possess the capability to revolutionize the approach to monitoring and managing cardiovascular and fetal health. These results underscore the importance of further exploration and development in this promising area of study.