DIGITAL SMART HEALTH VIA PHYSIOLOGICAL SIGNAL SENSING AND LEARNING

by

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ABSTRACT

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Periodic blood volume change underneath a person's skin induces subtle color variations in the skin area. These subtle changes can be captured by a noninvasive and low-cost optical technique called photoplethysmography (PPG). In this dissertation, we study the modeling of contact-based and contact-free PPG signals to facilitate its promising applications in physiological signal sensing and learning for digital smart health.

In the first part of the dissertation (Ch. 2), we propose a user-friendly and continuous electrocardiogram (ECG) measurement with the help of contact-based PPG sensors for long-term cardiovascular health monitoring. ECG is a clinical gold standard for non-invasive cardiac diagnosis but continuous ECG monitoring is challenging. PPG provides a low-cost alternative, though it provides less clinical knowledge compared to ECG. How to leverage the advantages of these two measurement modalities for better and easier healthcare? We first study the physiological and signal relationship between PPG and ECG and then infer the waveform of ECG via PPG based on their relationship. Joint

dictionary learning frameworks are proposed to learn the mapping that relates the sparse domain coefficients of each PPG cycle to those of the corresponding ECG cycle. This line of research has the potential to fully utilize the easy measurability of PPG and the rich clinical knowledge of ECG for better preventive healthcare.

In the second part of the dissertation (Ch. 3), a physiological digital twin for personalized and continuous cardiac monitoring is developed. Using our proposed dictionary learning based framework as the backbone model, this part of the dissertation focuses on the problem of inferring ECG signals from PPG signals under realistic conditions where available ECG data are scarce. With transfer learning, a generic digital twin model learned from a large portion of paired ECG and PPG data is fine-tuned to precisely infer the ECG from the PPG of a target participant whose available ECG data are scarce. Experimental results validate the feasibility of using the proposed method to learn a reliable digital twin for precision continuous cardiac monitoring. Convolutional neural network based backbone model designs are also proposed based on the underlying physiological process of ECG generation for better explainability with more flexibility in transfer learning.

In the third part of the dissertation (Ch. 4 and Ch. 5), we present contactless methods of blood oxygen saturation (SpO_2) measurement from remote PPG signals captured by regular RGB smartphone cameras. Both a principled signal processing based method and a data-driven neural network based method are proposed for SpO_2 estimation by either explicitly or implicitly extracting features from multi-channel skin color signals with color channel mixing and temporal analysis. Experimental results show that our proposed methods achieve better accuracy of blood oxygen estimates compared to traditional methods using only two color channels and prior arts.