Poster: Personalized Health Monitoring via Vital Sign Measurements Leveraging Motion Sensors on AR/VR Headsets

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ABSTRACT

Augmented reality/virtual reality (AR/VR) headsets have attracted millions of users and gained predictable popularity. However, long-period usage of immersive technology may lead to health issues (e.g., cybersickness, anxiety). In this poster, we design a low-cost and personalized healthcare monitoring system grounded on vital sign tracking (i.e., breathing and heartbeat rate tracking), by exploiting built-in AR/VR motion sensors. The key insight is that the conductive vibrations induced by chest and heart movements can propagate through the user's cranial bones, thereby vibrating the AR/VR headset mounted on the user's head. To realize this system, we design signal processing techniques to cancel the human motions and derive the periods of breathing and heartbeat through frequency-domain analyses. We further design a user identification scheme based on respiratory and cardiac biometrics, which works with vital sign monitoring to provide personalized healthcare recommendations. Our experiment shows that the proposed scheme can achieve less than 5.7% error rate on breathing/heartbeat rate estimation and 95% accuracy on user identification.

CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile computing**.

KEYWORDS

AR/VR headsets; Vital sign monitoring; User identification

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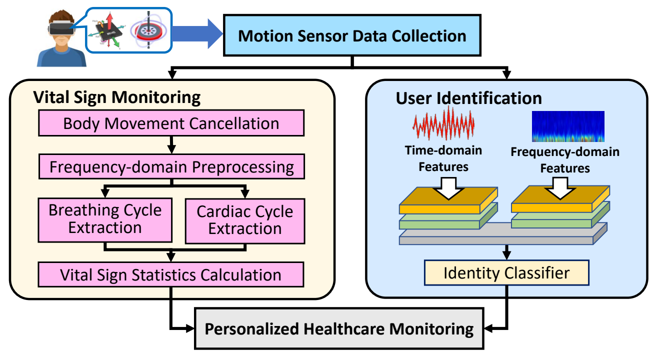

Figure 1: The architecture of the designed personalized health monitoring system based on vital signs.

1 INTRODUCTION

As the number of AR/VR users reaches a milestone of more than 150 million [2], immersive technologies have been increasingly adopted in many applications, including but not limited to immersive gaming, virtual shopping, virtual tourism, and education. With this growing trend, the health issues brought by the long-time usage of fully-immersive technology have become important public concerns. For example, the excitement and depression caused by long-period immersive gaming can be incentives for health problems (e.g., sleep deprivation, vision loss and dizziness). In addition, cybersickness, which is probably caused by the unsynchronization between body motion in real-world and content from virtual environments, has been widely reported in AR/VR communities. As vital signs (e.g., breathing and heartbeat patterns) carry critical information with respect to human's health status, it is desirable to have a vital sign monitoring and estimation solution that serves as a fundamental building block of commodity AR/VR devices, which will facilitate user's wellbeing monitoring, health management and personalized healthcare recommendations.

Traditional methods of vital sign monitoring rely on specific sensors (e.g., ECG/PPG sensors). These sensors are usually not available on mainstream AR/VR devices. A user may need to use additional wearable devices for vital sign tracking [1, 3], which will introduce extra equipment cost. Moreover, when conducing vital sign monitoring, the users need to wear or attach these specific sensors on their own body, which will induce inconvenience and bad experience for users. Grounded on these concerns, in this poster, we aim to design a continuous, low-cost, and personalized vital sign monitoring system by exploiting *subtle facial vibrations*. The key insight is that the conductive vibrations induced by chest and heart movements can propagate through the user's body and cranial bones, which vibrate the face-mounted AR/VR headset and impact

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the motion sensor readings. We summarize the main contributions of this work as follows:

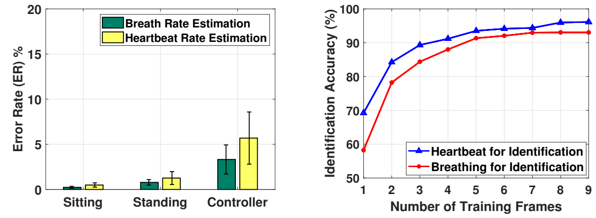
- We show that vital signals, including both breathing and heartbeat, can be reflected in subtle facial vibrations captured by AR/VR motion sensors. We design a continuous, low-cost, and personalized vital sign monitoring system without requiring any additional sensors.
- We design a series of signal processing methods to remove the random body movement artifacts. Frequency-domain analyses are then performed to estimate the breathing and heartbeat rates and the error rates are less than 5.7%.
- We design and implement a user identification model leveraging respiratory and cardiac features from both time domain and frequency domain, which can achieve more than 95% accuracy on user identification, and it shows the potential to work with vital sign monitoring module to provide user-specific healthcare recommendations.

2 SYSTEM DESIGN

Our system aims to realize both vital sign monitoring and user identification with facial vibrations. The overview of the system is illustrated in Figure 1. The vital sign monitoring module will provide accurate estimations of the breathing and heartbeat rates of the user, while the user identification module is to derive user identity based on biometrics encoded in respiratory and cardiac patterns.

Vital Sign Monitoring. Our system collects the motion sensor readings in the background and operates in short-time frames (around two seconds) for continuous vital sign monitoring. We choose the z-axis accelerometer readings as the motion sensor inputs, which capture the most obvious and regular changes of muscle movements related to human's breathing and heartbeat. For each frame, our system first cancels the impacts of random body motion artifacts with a threshold-based method. We apply short-time energy (STE) to detect frames impacted by body motion if the energy of current frame is larger than a pre-defined threshold. We remove the corresponding frames to ensure robust vital sign measurements. We use two different level 2 Butterworth Bandpass Filters with cut-off frequencies of $0.1Hz \sim 0.5Hz$ and $0.8Hz \sim 3.0Hz$ to extract breathing and heartbeat signals, respectively. Fast Fourier Transform (FFT) with Hann Window is applied to reveal the period of the signal, and then a peak selection algorithm will be utilized to determine the breathing/heartbeat rate measurement.

User Identification. In this module, we employ a convolutional neural network (CNN) model to perform user identification. The respiration/heartbeat waveforms and FFT spectrograms extracted from the vital sign monitoring module will serve as the input of the user identification module. For time-domain waveforms, a feature extractor is employed to extract statistic and cardiac features in time domain. We also implement a CNN-based representation extractor to extract the hidden representations from frequency domain spectrograms. Features from time-domain waveforms and frequency domain spectrograms are concatenated and fed into an identity classifier to predict the user's identity.



(a) Error rate of measurement (b) Identification accuracy

Figure 2: Accuracy on vital sign monitoring and user identification using different time domain waveforms

3 PRELIMINARY EVALUATIONS

Vital Sign Monitoring. We collect data from 20 different users (14 males and 6 females) by using a Meta Quest VR headset to evaluate our vital sign monitoring module. The data is collected under three scenarios, including sitting still, standing still, and using the controller while sitting. The duration of data collection for each subject per scenario is one minute. A respiration belt and an ECG monitor are used to collect the ground truth of breathing and heartbeat rates, respectively. We use the Error Rate (ER) of breathing rate and heartbeat rate as the metrics and the results are shown in Figure 3(a). We can find that the average ERs of breathing rate estimation under three different scenarios are less than 3.3%. The average ERs of heartbeat rate estimation can also achieve less than 5.7%. For relatively static scenarios, including sitting and standing, the average ERs in these scenarios are less than 1.3%. The results demonstrate the effectiveness of our vital sign monitoring module.

User Identification. We also evaluate the performance of user identification of our system using breathing and heartbeat waveforms as the input of time-domain signals. We examine the user identification performance under different numbers of training frames. Figure 3(b) shows the user identification accuracies of our user identification module. We find that our system can achieve more than 95% when using only 6 frames for training. In addition, the identification accuracies are consistent when using both breathing and heartbeat waveforms as input, which demonstrates the effectiveness of our user identification scheme. Moreover, the accuracies are still over 90% even with only 3 frames for training, which proves the low training requirement of our system.

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