CoRSA: a Cardio-Respiratory Monitor in Sport Activities

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ABSTRACT

We present the system CoRSA to incorporate integrated sensors in millimeter-scale packages for continuous cardiorespiratory (CR) evaluation in sports activities. CoRSA retrofits trending sports apparel to add on CR sensing capability. The system uses an air pressure sensor inside a vented mask to approximate a spirometer, and an earlobe pulse-oximeter (PO) to monitor heart rate (HR) and oxygen saturation (SpO2). CoRSA also includes an inertial measurement unit for tracking activity and future study on motion artifact correction on the CR signals in active sports. An aerobic exercise evaluation is also performed which shows results similar to sports studies using bulkier conventional medical equipment in the CR signals' characteristics.

CCS CONCEPTS

• **Applied computing → Consumer health**.

KEYWORDS

Cardiorespiratory Monitoring; Wearable Sensing; Sport Activity Tracking; Multi-modal Sensing

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1 INTRODUCTION AND BACKGROUND

Cardiorespiratory (CR) signals are a group of vital signs that reflect the ability of the cardiovascular and respiratory systems to supply our body with oxygen. Oxygen delivery is essential for evaluating overall health and fitness [4].Non-invasive CR evaluation includes the lung's function tests (such as spirometry) and heart tests. Heart tests include electrocardiograph (ECG), blood flow tests (pulse-oximetry), etc. These vital signs are commonly tested during patients' diagnosis and athletes' performance evaluations.

Our vision is that a lightweight, simple and unobtrusive wearable functional apparel for continuous CR evaluation can be used by fitness goers and professional athletes in their existing training routines, instead of dedicated CR check up sessions in special facilities. Instead of conventional sensing elements, our vision looks at the potential of system-in-package (SiP) and system-on-chip (SoC) sensors that are popular in the wearable computing community. Such functional apparel should be built on innovative sensing technologies and smart data interpolation methods so that miniaturized sensor systems can best represent conventional complex ones. The apparel should also be able to offer styling possibilities for fashion designers.

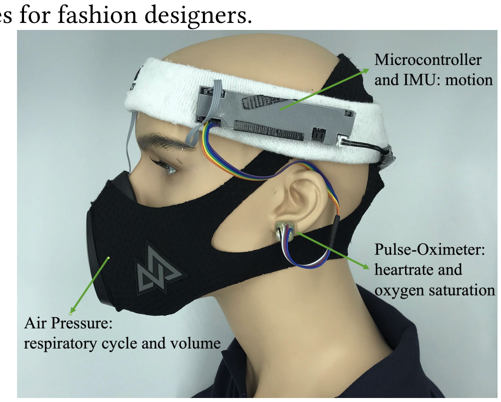

Figure 1: The whole system worn on a mannequin.

2 THE CORSA HEAD-WORN SYSTEM

The first CoRSA prototype is build on off-the shelf sportswear and electronic modules. As shown in Figure 2, an Arduino module Adafruit Feather Huzzah32 is used to control the sensors and transmit data through Bluetooth to an Android phone. The system includes three sensors: BME280 that measures the air pressure; BNO055 IMU that measures the physical motion; MAX30102 pulse-oximeter The effectiveness of using BME280 for wearable spirometry is demonstrated in [1]. The data processing for the pulse-oximeter is implemented according to [3]. The valve in the mask is removed,

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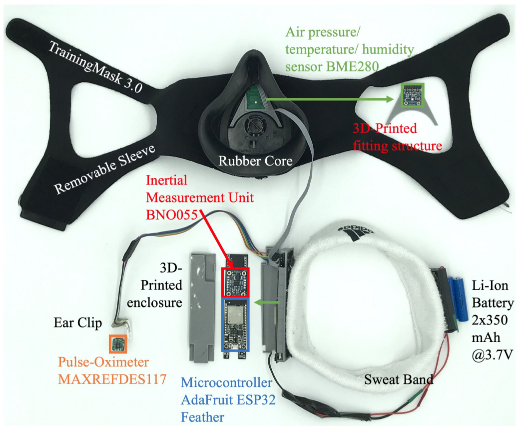

Figure 2: CoRSA's spread-out system structure, some components are duplicated for illustrative purpose.

so that the wearers can breath without restriction. A 3D-printed fitting support structure is designed, which ensures a fixed position and orientation of the air pressure sensor BME280 inside the core. A sweat band is used to carry the remaining electronics on the wearer's head. A clip-on earring is used to fix the pulse-oximeter sensor on the wearer's ear lobe. The sweatband and the masks' sleeve can be washed.

3 AEROBIC EXERCISE EVALUATION

To test CoRSA's performance in sport activities, we conducted an aerobic training experiment with five participants (1 female and 4 males) between the age of 22 to 27. They wore a finger PULOX device (Contac Medical) on their index finger, and pinched the device in position during the exercise using the thumb. People's heart rate is normally constant and oxygen saturation is close to 100% when idle. In such conditions, the pulseoximter sensor of CoRSA and PULOX always have the same readings. The aerobic exercise experiment is conducted to introduce changes in HR and SpO2 by gradually increase the participants' cardiorespiratory activity.

They are asked to exercise with a stationary cycling machine (Star Trac) for 4 consecutive bouts, each lasts for 5 min. Between each bout, they can rest on the machine for approximately 1 min, but the resting duration is not fixed due to different participants' fitness. To ensure the exercise intensity level, the participants pick a cycling resistance level and keep it for the rest of the experiment, and try to maintain the revolutions per minute between 70 and 80.

Fig. 3 shows the result from participant 1. The bottom plot shows the linear acceleration, from which the cycling and resting periods are clearly visible. The high motion period before the first cycling session is the setting up and preparation of the experiment. The first plot shows the respiratory pressure measured by the BME280 sensor in the CoRSA system. The second and third plots show the HR and SpO2 results from both the CoRSA and PULOX devices. During

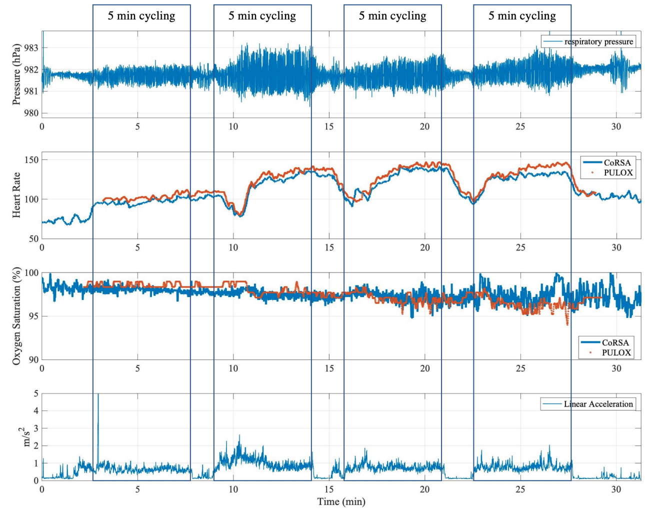

Figure 3: CoRSA's cardiorespiratory and motion measurement of the aerobic session from participant 1.

the recording, the PULOX device is generating valid data according to its software. From the second plot, it appears that both HR readings coincide with each other in the overall trend and also some micro-fluctuations.

PULOX is not rated for reliable measurement while the person is moving. During the experiment, we observed the PULOX was not always generating valid data for participant 3 and 4. When the PULOX data is valid, the MAX30102 from CoRSA offers similar results. Through careful visual comparison between the IMU data and the photodetector's raw data, we did not observe any motion artifact. Our future research scope also includes implementing various motion artifact correction algorithms such as those in [9] [5].

4 FURTHER DISCUSSIONS AND CONCLUSION

In Fig. 3, we can observed the respiration magnitude and HR are closely related. From all the different bouts of all participants, there are observable delays of respiration magnitude and HR increments from rest to the start of the exercise, and recovery delays after the exercise. Even though the SpO2 is quite noisy in both devices, as expected for PO in active motion, both values decrease as the person performs longer aerobic exercises. The results agree with the findings from many medical researches such as [7][6][8][2].

In conclusion, CoRSA is a lightweight system that enables existing sports apparel with cardiorespiratory monitoring capabilities with SoC and SiP sensors. Thus the similar apparel with different styles can all be CoRSA-enabled. By doing so, the CR performance evaluation methods that are used periodically for pro-athletes can be brought into not only their continuous training, but also to the leisure athlete market. The system also offers fully synchronized respiratory, pulse-oximetry and motion data, which can help further studies during active sports.

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