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Multi-Camera Motion Compensation for Remote Monitoring of Heart Rate and Respiration

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Abstract: We demonstrate a motion-tolerant vital signs monitoring using multiple, depth sensing cameras. Results show successful isolation of the respiratory waveform from walking motion and successful isolation of heart rate from swaying motion. © 2021 The Author(s)

1. Introduction

Advancements in imaging technology have made it possible to measure cardiorespiratory signals remotely [1]. Non-contact acquisition respiratory rate and heart rate is typically performed via remote photoplethysmography (PPG) [2,3] or depth-based motion tracking [4]. Depth-based approaches measure respiration by tracking chest motion due to the expansion and contraction of the lungs, and measure heart rate by tracking subtle head movements due to pulsation. A disadvantage of non-contact methods is their susceptibility to motion artifacts, which can result from common movements such as walking or swaying. To increase motion tolerance in depth-based acquisition of vital signs such as respiration or heart rate, we demonstrate a multi-camera configuration that uses region of interest (ROI) referencing to account for gross body movements.

2. Experimental Results

The experimental setup is shown below in Figure 1(a-b). Two cameras are mounted on opposite sides of the subject, at a total distance of 4 m apart, which record the subject from the front and the back. The resolution of each camera is 2.5-5.0 mm across this distance. The cameras (front camera: Intel® RealSense™ D455; back camera: Intel® RealSense™ D435i) are equipped with visible/near-infrared sensor (400-865 nm), an 850 nm structured light projector, and two sensors for depth visualization. Datasets are recorded at 90 fps. To reduce depth noise by a factor of $\sqrt{3}$, every 3 frames are averaged, which yields an effective frame rate of 30 fps. A wireless pulse oximeter (Masimo MightySat® Rx) was used as a reference.

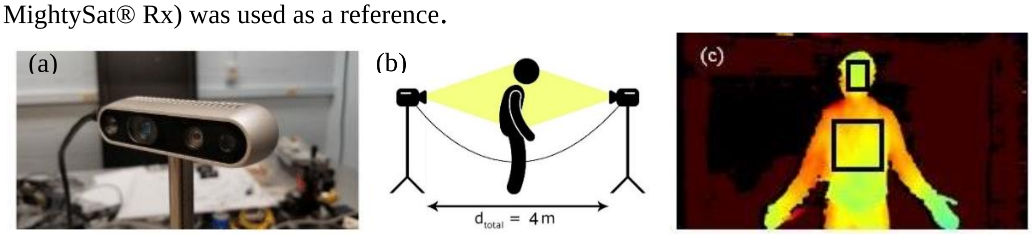

Fig. 1. (a). Camera setup with frame-sync triggering. (b). Experimental setup. (c). A frame from the depth channel with chest and face ROI.

The depth distance is analyzed using a ROI on the subject's chest/back area, which is shown in Figure 1(c). Earlier studies have shown that the respiratory waveform can be isolated from walking motion using a multi-camera approach with the following equation [5]:

$$d_{thorax}(t) = d_{total} - d_{frontcamera}(t) - d_{backcamera}(t) \quad (1)$$

We extended this technique to larger distances and applied it to five different participants, in order to isolate the respiratory waveform from significant body motion, specifically where subjects walk back and forth over a distance of 2 m. A single trial of respiratory waveform isolation is shown in Figure 2(a-c). Figure 2(a-b) shows the depth signals $d_{frontcamera}(t)$, $d_{backcamera}(t)$, and $d_{thorax}(t)$. Figure 2(c) shows the bandpass filtered signal, from which the respiratory rate can be estimated. In this experiment (n=5), the mean difference between the reference device respiration rates and estimates produced by our system was -0.76 ± 0.76 breaths/min and -2.62 ± 1.38 breaths/min for a standing and walking subject, respectively (i.e., mean ± standard deviation).

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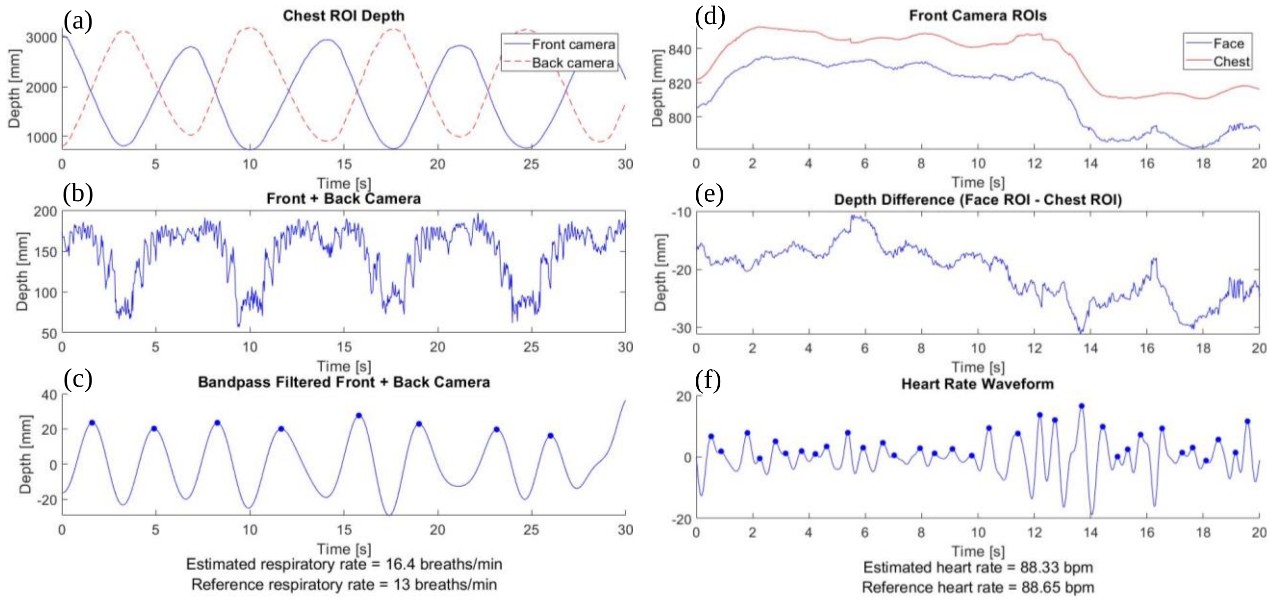

Fig. 2: (a). Front and back camera chest ROI waveforms. (b). Thorax depth waveform from front and back chest ROIs. (c). Isolated respiratory waveform. (d). Front camera face and chest waveforms. (e). Depth difference of face and chest ROI exhibits reduced motion artifacts due to swaying. (f). Isolated heart rate waveform.

To extract heart rate from depth, an ROI was placed on the subject's face, shown in Figure 1(c). We isolate head movement, which contains depth changes associated with heart rate, from overall body movement, using the front camera. The head movement, obtained by depth evaluation of two different front camera ROIs, is defined as:

$$d_{head}(t) = d_{front\ face\ ROI}(t) - d_{front\ chest\ ROI}(t) \qquad (2)$$

Figure 2(d-f) shows isolating heart rate from movement when the subject is standing. Figure 2(d) shows the depth waveforms for the face and chest ROIs. Figure 2(e-f) shows the $d_{head}(t)$ waveform, which exhibits less sway or motion by removing body movements, and the isolated heart rate waveform. Our earlier studies show that heart rate can be isolated from head depth changes in sitting participants [6]. In these studies, the RMS head depth change while sitting was 3 mm, while the heart rate related depth change was approximately 1 mm. Our evaluation (n=5), shows that the average depth change while standing increases to 37 ± 9.43 mm. Subtracting the chest ROI from the face ROI reduced swaying to an average of 18 ± 4 mm. After reducing the average sway, the mean difference between the reference device heart rates and our system decreased to -2.32 ± 3.56 bpm, compared to -3.97 ± 6.58 bpm prior to motion reduction. In this case, reducing body motion improved heart rate isolation in some trials, but was not crucial in a distance of 1 m. In a scenario described in Figure 2(a-c), isolating heart rate from larger movements, is more challenging because depth changes due to walking are much greater than those due to pulsation.

3. Conclusions

A multi-camera system was evaluated for isolating respiratory rate and heart rate from movement motion in five subjects. Respiratory rate was successfully isolated from walking subjects. Subtracting the face and chest ROIs depth values using the front camera reduced the effect of swaying on the depth waveform but was not critical for isolating heart rate in a short distance. Algorithms that evaluate multi-camera and multi-ROI depth changes, are currently evaluated for extracting heart rate from larger body movements, such as walking.

4. References

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