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Verification of using radar vital sign monitors in deception tests (2023)

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Abstract. This study examines the validity and accuracy of a typical radar-based vital signal monitoring system during spoken responses, a common and necessary scenario in deception tests. Traditional deception tests, such as polygraph tests, often involve testees wearing numerous electrodes, which can induce nervousness and affect their physiological measurements. Additionally, testers may be hindered by the potential Hawthorne effect caused by such varied measurements, while the movement and behavior of testees are typically restricted to ensure data validity. Based on the conclusive findings of this paper, practitioners can employ radar technology to non-invasively extract crucial vital signs during deception tests, ensuring validation. This approach enhances efficiency and affords greater flexibility to testers.

Keywords: Millimeter Wave Radar, Vital Sign Monitor, Deception Test

1. Introduction

Detecting deception has been a longstanding challenge in criminal investigations, with traditional techniques relying heavily on complex instruments and suffering low effectiveness. One of the most commonly used tools is the polygraph test, which measures physiological processes to identify changes that may indicate deception. However, the need for multiple electrodes in the traditional polygraph tests may put heavy physiological pressure on the testee, leading to potential Hawthorne effect, influencing results to have limited effectiveness of this approach.

Researchers have examined several novel techniques to acquire such significant vital signals that correlate strongly with deceptive behaviors in a non-contact way [1], including facial analysis and radar vital signal monitors (RVSM). However, most of the studies ignored the complex confounding environment during the virtual polygraph tests, making such novel techniques unvalidated to come into service. Despite the rapid development in both sensor industries and psychological field, conventional polygraph tests still utilize abundant sensors with touch-type electrodes to ensure the accuracy of measurements, leading to ever-present tedious processes and obstructing from potential Hawthorne effect.

In this paper, we introduced a typical RVSM system with a 77GHz FMCW radar and tested the feasibility of using such a system to acquire stable heartbeat and respiration signals while talking, as a common confounding issue during a deception test. It is notable that some traditional polygraph test requires testees not to speak and to write down their answers in a notebook instead, avoiding possible interferential signals.[2] Hence, if the typical RVSM system could exclude such confounding, it would be a significant method that is more stable and effective rather than traditional methods.

2. Literature review

This section focuses on examining previous research conducted in relation to our system. It includes a comprehensive review of papers that are relevant to the parameters utilized in our system.

In the context of traditional polygraph testing, it is widely recognized that heart rate extracted from an electrocardiograph signal, breath rate, and other bioelectricity waves such as electroencephalography exhibit a strong correlation with deceptive behavior [2]. Recent studies have explored the use of neural networks to directly classify such bioelectricity waves rather than simply analyzing their frequencies [3]. Despite progresses in signal processing methods [4], however, the fundamental signal measuring techniques have remained largely unchanged, with testees still experiencing discomfort from the use of multiple electrodes, and testers being confounded by the potential Hawthorne effect and the need for complex instrumentation.

Hence, Researchers have also bent themselves to develop some easy-accessible techniques to acquire these significant vital signals. One of these projects led by Georgia Tech Research Institute (GTRI) [5] was intended to extract vital signals including heartbeat and respiration from received chest displacement data using a frequency-modulated radar. Despite the GTRI system being military-oriented, as a non-contact battlefield vital sign monitor [6], researchers have made hypothesis of utilizing such radar vital signal monitors in the field of deception detection, albeit not in-depth case study [7].

In the context of RVSM systems, mature solutions, elaborated basis, and demo algorithms are provided by the Texas Instrument Developer Zone [8]. To calculate the nuance in displacements from the testee's chest, we measure the change in phase of the FMCW signal with time, with the basic equation $\Delta\Phi_b = \frac{4\pi}{\lambda}\Delta R$, where $\Delta\Phi_b$ represents the change in phase with the displacement of ΔR, and λ represents baseband frequency. Hence, the higher λ goes, the more resolution we can get. Compared to the 2.4GHz FM radar used in the GTRI project, the IWR-1642 radar module that we utilize provides a starting frequency at 77GHz and advanced DSP with 4GHz bandwidth, ensuring the theoretical resolution of the system to exceed 0.05mm, far enough for measuring displacement parameters due to heartbeat.

3. Proposed system

The entire system consists of two subsystems: one for detecting vital signals using radar and another utilizing optical sensors. Within the radar-based subsystem, electrocardiogram (ECG) and respiration waves are extracted from filtered displacement data acquired from the human chest. This extraction is accomplished using a fundamental algorithm provided by Texas Instruments' Radar Vital Signal Lab [8], in conjunction with the IWR1642 77GHz FMCW radar hardware. In the optical-based subsystem, an APDS9008 laser pulse sensor is connected to a microcontroller unit (MCU) for real-time processing of pulse signals using the light volume method. The processed signals are then outputted through a serial interface. Both subsystems are connected to the same upper computer, enabling the alignment of time-series data based on timestamps provided by the computer. The entire system is

4. Experiment methods

Note that the database from experiment (a), (b), and (d) are collected during a volunteered ethical condition. Time series data of in total of 2 minutes, including optical electrocardiograph and chest displacement data are gathered from each of the ten volunteered adult participants. Experiment (c) is the self-acting case study conducted by the author himself. All the data preprocesses are operated by the MCUs, while the analysis is conducted using MATLAB software.

a) Accuracy of RVSM systems in case of steadily sitting

This test was intended to ensure the validity of the operational RVSM system, and to act as a control group rather than experiment (b). Both the RVSM system and optical-based system were set up and connected to the same upper computer. The antenna of the radar was pointed to the frontal side of the testee's chest, with the optical pulse sensor tied to the right index finger of the testee. Each of the ten participants is asked to sit still and stay resting, while time series data from both radar and optical-based systems are recorded at a rate of 20Hz for 60 seconds.

b) Accuracy of RVSM systems in case of talking

This test was intended to test the validity of the operational RVSM system in case of talking, and to act as the experiment group rather than experiment (a). Both the RVSM system and optical-based system were set up and connected to the same upper computer. The antenna of the radar was pointed to the frontal side of the testee's chest, with the optical pulse sensor tied to the right index finger of the testee. Each of the ten participants is asked to relax and read aloud the same material, while time series data from both radar and optical-based systems are recorded at a rate of 20Hz for 60 seconds.

c) Case study on speaking rate

This test was intended to examine the origin and attribution of the discovered interference wave in experiment (b) as a case study. Another subsystem consists of a MCU and an LED was introduced to produce a manipulated rated blink, while the RVSM system was set up and connected to the upper computer. The antenna of the radar was pointed to the frontal side of the testee's chest, while the testee was asked to make a syllable of "Ah" when the led blinked. Time series data from the radar was recorded at a rate of 20Hz for 30 seconds, while the experiment was repeated with the varied speaking rate of 2Hz (2 syllables per second), 3Hz, 4Hz, and 5Hz.

d) Accuracy of RVSM systems detecting from back

According to online literature [8], the displacement of body surface displacement parameters due to breathing and heartbeat are smaller when measuring from the back rather than from the front with RVSM systems.

Table 1. Typical indicators of body surface displacement

		From front	From back
Vital signals	Frequency	amplitude	amplitude
Breathing Rate (Adults) ~	0.1 – 0.5 Hz	~ 1- 12 mm	~ 0.1 – 0.5 mm
Heart Rate (Adults)	0.8 – 2.0 Hz	~ 0.1 – 0.5 mm	~ 0.01 – 0.2 mm

This test was intended to examine whether the affirmative interference wave in experiment (c) will also be remitted in case of measuring radar vital signals from the back of the testee, and to act as the experiment group rather than experiment (a). Both the RVSM system and optical-based system were set up and connected to the same upper computer. The antenna of the radar was pointed to the rear side of the testee's body, with the optical pulse sensor tied to the right index finger of the testee. Each of the ten participants is asked to relax and read aloud the same material, while time series data from both radar and optical-based systems are recorded at a rate of 20Hz for 60 seconds.

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5. Implementation and results

General output

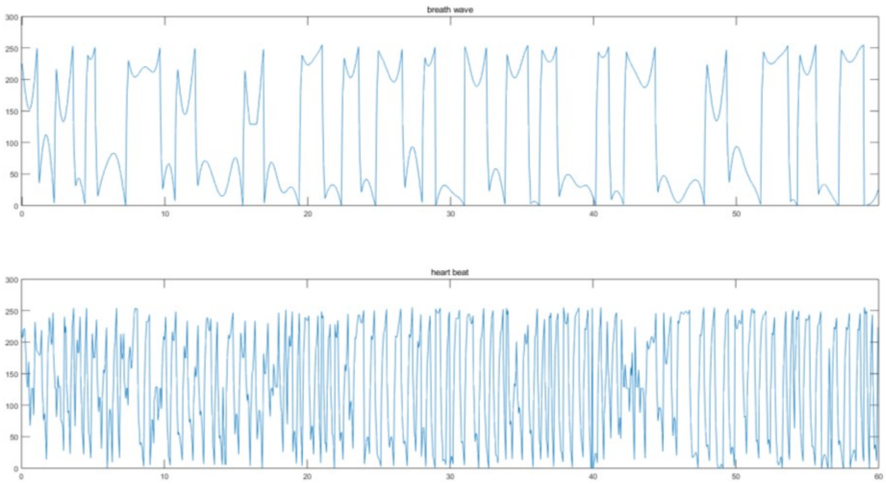

Figure 1. Breath wave and heart-beat wave

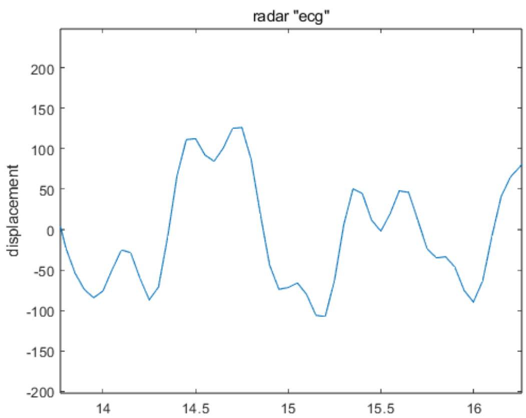

Figure 2. zoomed heart-beat waveform (Note that this graph shows displacement but not true ECG signals)

These figures show that the RVSM systems are competent for extracting respiratory waves and heartbeats from chest displacements. While a typical cycle of heartbeat in the extracted heartbeat waveform should contain two commutative peaks and troughs, representing the stretch and shrink of atrium and ventricle, respectively.

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a) Accuracy of RVSM systems in case of steadily sitting

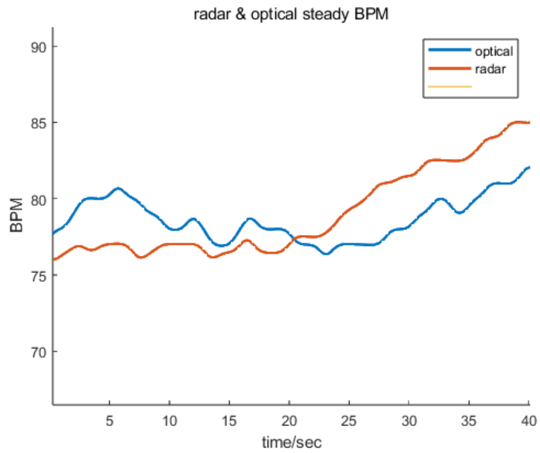

Figure 3. Heartbeat count from radar and optical sensors (Blue line represents value from optical sensors, Red line represents value from RVSM systems)

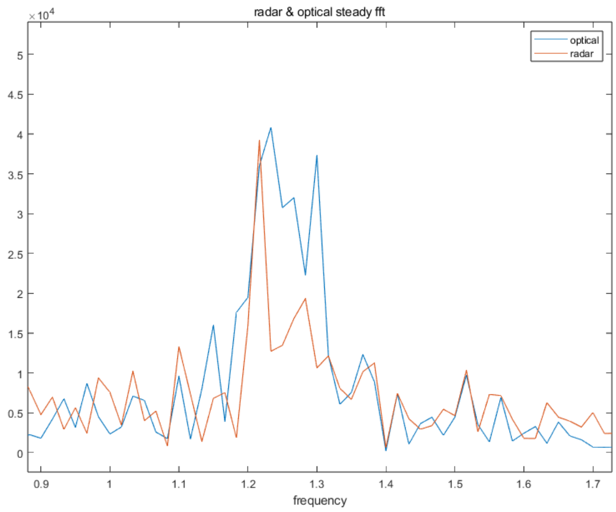

Figure 4. frequency-domain analysis of the data (Blue line represents value from optical sensors, Red line represent value from RVSM systems)

As shown in the figure, in this typical data from the steadily-sitting dataset, with the bumps count algorithm, the error between the RVSM system and the optical-measured system is below five bumps per minute, and the frequency analysis shows, in general, the same peaks. These results show that the RVSM system is competent for measuring heartbeats when the testee sits steady.

b) Accuracy of RVSM systems in case of talking

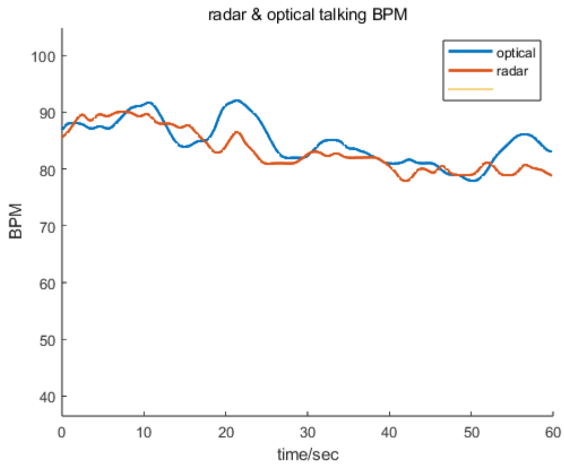

Figure 5. Heartbeat count from radar and optical sensors (Blue line represents value from optical sensors, Red line represents value from RVSM systems)

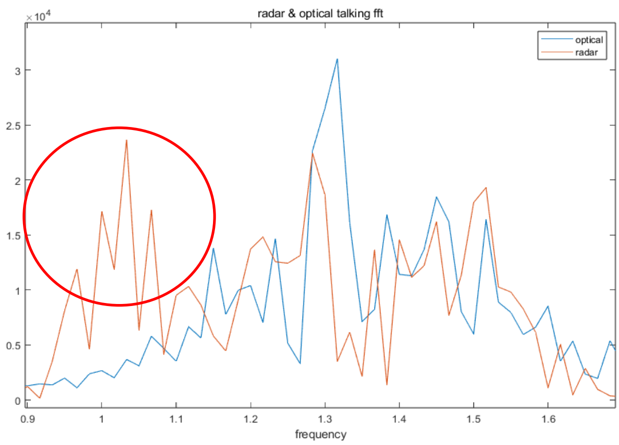

Figure 6. frequency-domain analysis of the data (Blue line represents value from optical sensors, Red line represents value from RVSM systems)

As shown in the figure, in this typical data from the reading-aloud dataset, with the bumps count algorithm, the error between the RVSM system and the optical-measured system is also below five bumps per minute, however in the frequency analysis, albeit both systems show similar central frequency of about 1,3Hz, which represents average heartrate, the frequency-domain analysis of data from RVSM systems shows several outstanding peaks of nearly identical height as the central peaks at lower frequencies. These results show that the RVSM system is competent for measuring heartbeats when the testee is talking, though introduces following research directions about the lower-frequency wave.

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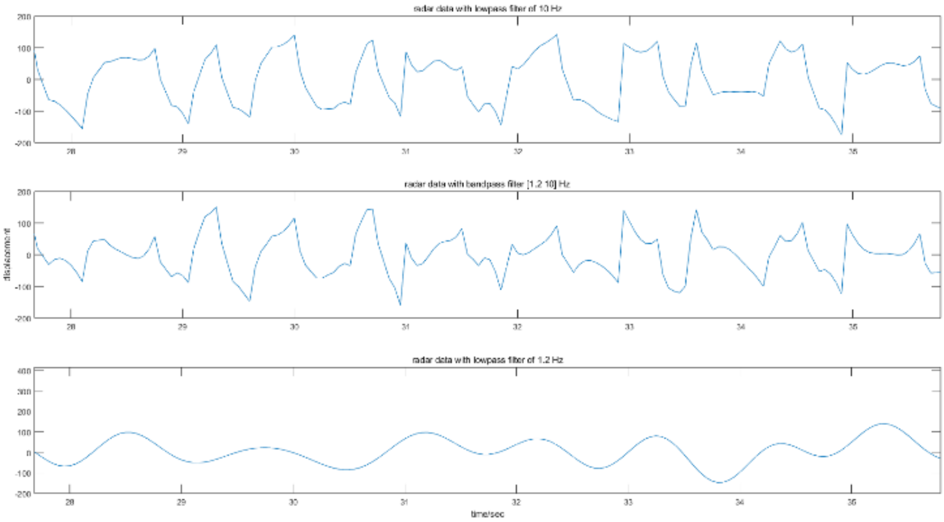

Figure 7. Filtered data of the above typical data (The first plot shows raw data, The second plot shows wave without the lower-frequency component, The third plot shows the lower-frequency component)

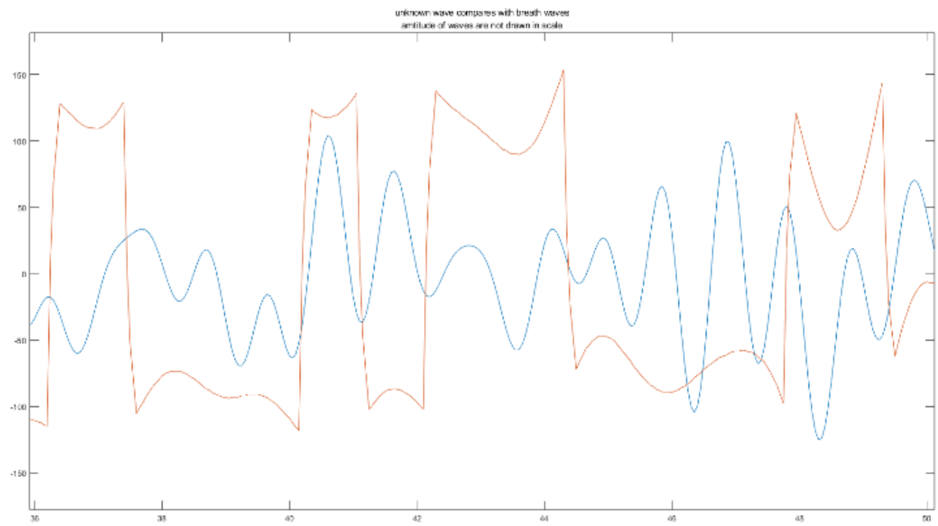

Figure 8. comparison of the lower-frequency wave and breath waves (Blue line represents the lower-frequency wave, Red line represents breath wave at the same time)

As shown in the figure, when a 1Hz lowpass filter is applied, there aren't many differences or typical features between the raw data and the filtered data, while the filtered lower-frequency wave also shows little relation with the breath waves.

c) Case study on speaking rate

In this case study, the attribution and features of the unknown lower-frequency wave are examined

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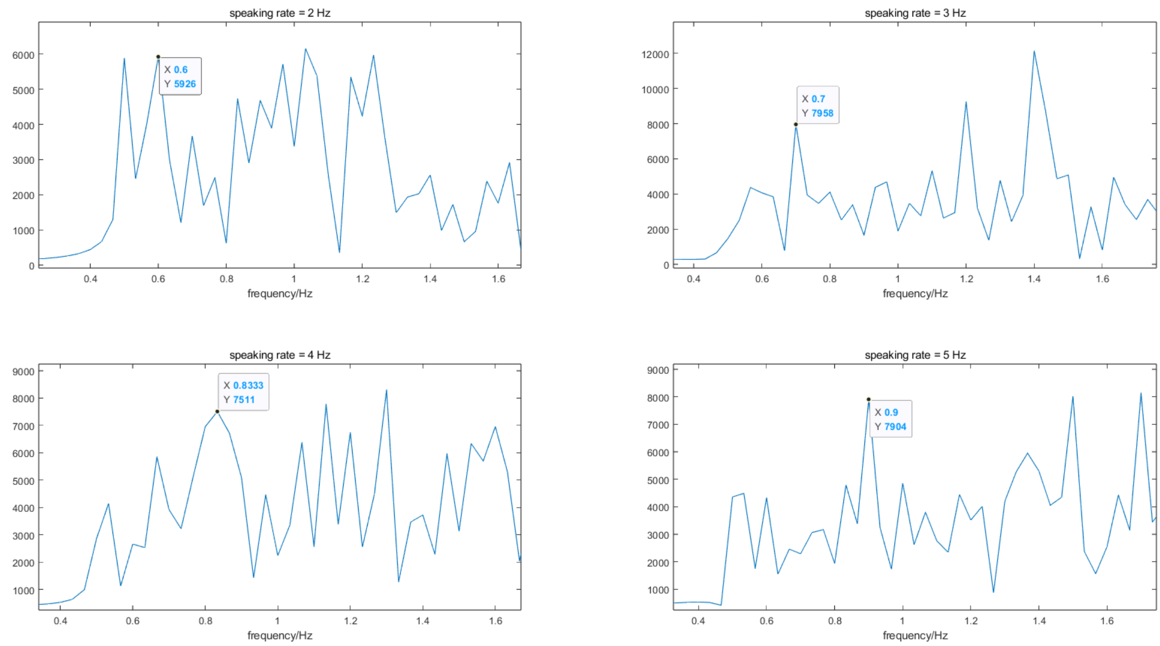

Figure 9. frequency-domain analysis of data in case of different speaking rates (peaks of the lower-frequency domain are labeled)

As shown in the figure, the central frequency in the lower-frequency domain (below 1Hz) increases as the speaking rate increases. However, we still don't know what these disturbing waves stand for.

d) Accuracy of RVSM systems detecting from back

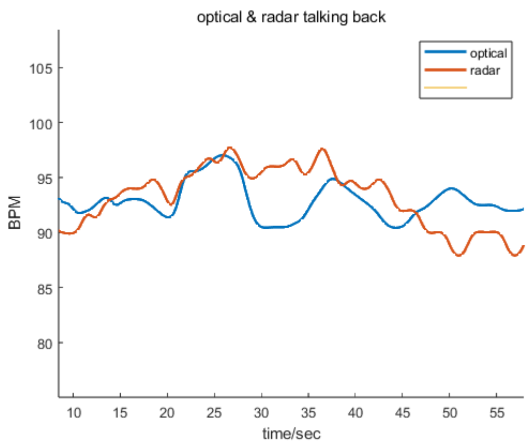

Figure 10. Heartbeat count from radar and optical sensors (Blue line represents value from optical sensors, Red line represents value from RVSM systems)

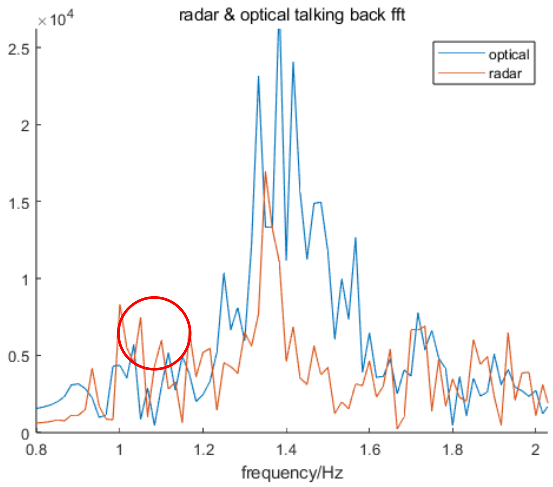

Figure 11. frequency-domain analysis of the data (Blue line represents value from optical sensors, Red line represents value from RVSM systems)

As shown in the figure, in the case of measuring from the back, data from RVSM systems still contain the mentioned lower-frequency disturb when the testee is speaking, though the error of bumps counts between the RVSM system and the optical-measured system is still below five times per minutes.

6. Conclusion

RVSM systems are compatible for measuring heartbeats and raspatory signals in cases where people are talking, as well as possible lie detections. However, according to the results from this study, talking would introduce an interferential frequency lower than 1Hz to extracted heartbeats. In addition, the frequency of the interferential wave is proportional to the speaking rate. At the speaking rate of 5 syllables per minute, the interferential frequency is about 0.9Hz. Hence, there's reason to suspect that in case of a possible speaking rate higher than 5 syllables per minute, or in case the average heartrate is lower than 60 bumps per minute (1Hz), the interferential wave would lead to an invalid heartbeat count. In supplement, measuring vital signals in the back would slightly weaken the confounding component, albeit not completely. However, the true cause of the formation of the lower-frequency component produced by the RVSM system has still not been examined, and the case study on the lower-frequency wave has not been generalized to multiple testees, leading to possible imprecise results.

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