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Core Sheath Fiber Based Photoplethysmography (PPG) Integration and Artificial Intelligence (AI) Outlook: A Non-Invasive Scheme for Infant Heart Rate Monitoring

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Abstract: Photoplethysmography (PPG) is a non-invasive physiological monitoring technology used in health monitoring, but traditional devices have limitations in infant health monitoring. This paper aims to improve the comfort and reliability of infant health monitoring by combining PPG with core-sheath textile technology. Core-sheath structural fibers are used as carriers for PPG sensors, resulting in non-invasive and comfortable heart rate monitoring. Signal processing algorithms like wavelet transform, ICA, and CNN are used to denoise PPG signals and extract heart rate. The proposed theory outperforms traditional methods in signal quality and heart rate detection accuracy, while improving wearing comfort. The PPG signal processing algorithm and AI interaction enable real-time heart rate monitoring, providing an innovative solution for infant health monitoring.

Keywords: Core-sheath fiber, Photoplethysmography (PPG), Artificial Intelligence (AI), Infants and young children, Heart rate monitoring, Non-invasive

1. Introduction

Heart rate monitoring technology is crucial for detecting infant health issues, especially when monitoring sleep conditions from the side. To ensure safety and reduce financial strain on guardians, the idea of integrating a heart rate monitor into infant clothing has been proposed. However, there is a research gap for the special needs of infants, particularly in the integration strategies based on photoplethysmography (PPG) and core-sheath structure fibers. This paper explores the combination of PPG technology and core-sheath structure fibers for monitoring infant heart rate. The paper uses inductive summary, comparative analysis, and case analysis methods to analyze the PPG signal processing algorithm and prove the feasibility of the infant smart clothing integrated with PPG and core-sheath fibers. The paper also reviews the interaction and application scenarios of this theory and AI, predicting the longer-term prospects of smart clothing. As technology advances, it is expected to be extended to more people and provide more convenient and comfortable tools for health management.

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2. Current status of the smart clothing market and the development of electronic engineering integrated into fabrics

2.1. Flexible Sensor

The smart clothing market has grown significantly due to the integration of electronic engineering and textiles. Flexible sensors and biosignal detection technologies have advanced, promoting the transition from consumer to medical-grade clothing. Traditional core-spun yarn and new electrospinning methods offer advantages in stability and strain tolerance, facilitating commercial manufacturing and implementation in smart textiles for monitoring human movement and health status [1].

2.2. ECG signal detection

In the process of integrating electronic engineering with fabrics, ECG signal monitoring has made significant progress in the field of smart clothing. For instance, fabric-based ECG dry electrodes have become a method to replace clinical wet electrodes. Dry electrodes include non-contact or conductive fabric electrodes, which can achieve long-term biosignal measurement. A number of scholars have incorporated ECG dry electrodes into elastic bands and bracelets and investigated their practicality, thereby validating the efficacy of dry electrodes in ECG signal monitoring. Chois et al. have also designed and developed a new sensor for sleep monitoring that can be used for aerospace applications [2].

2.3. PPG heart rate monitoring

In addition, in contrast to ECG, which is susceptible to motion artifacts, the frequent activities of infants and young children will interfere with the stability of electrode contact, resulting in data loss or increased noise. On the other hand, PPG has increasingly become an ideal option for infant health monitoring. It offers advantages such as non - contact operation, high comfort, and resistance to motion - induced interference. In recent years, PPG technology has reached medical maturity in consumer products. For example, the MYZONE smart sports bra sold on the market uses PPG and ECG technology, and the deviation from the electrocardiogram is as low as 0.4 times per minute. This provides a mature precedent for the practice of PPG core sheath infant clothing. In the future, the app can intuitively display the baby's heart rate and provide accurate real-time alarms to enhance parents' trust in the product [3]. The Apple Watch also uses PPG technology, which has reached medical maturity in consumer technology and is relatively accurate in measuring sinus rhythm heart rate [4].

2.4. Summary

Smart clothing is constantly developing, with heart rate monitoring functions entering the public eye. However, existing research and products may not be suitable for infants, a special consumer group. ECG monitoring usually requires multiple electrode patches to directly contact the skin and use conductive gel, which can cause allergies or discomfort for infants with delicate skin. PPG sensors can be integrated into soft textile fibers without direct contact, improving infant comfort. When combined with appropriate optical design and AI algorithms, PPG can compensate for motion artifacts and improve data reliability. PPG combined with core sheaths can meet the special needs of infants, making clothing with heart rate monitoring functions more suitable for this special consumer group.

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3. Analysis of core-sheath fiber and the principle of photoplethysmography (PPG)

3.1. Unique structure and working mechanism of core-sheath fiber

The core-sheath structure is a design that consists of a core layer and a protective layer, with a photoelectric sensor embedded in the core layer. This design provides comfort, flexibility, and adaptability to changing body shapes, allowing clothing to be worn like ordinary clothes without restricting activities. Additionally, the embedded sensors and technology prevent the appearance of external devices, making the clothing look like ordinary clothes.

3.2. Technical principles and applications of photoplethysmography (PPG)

PPG is the measure the volumetric changes of the heart by measuring light transmission or reflection. During systole, the increase in pressure forces a forward pulse into the blood vessel. The PPG device shines light on the skin to detect a pulse by measuring the difference in the quantity of light reflected back to the sensor. Typically, the sensor is usually placed on the skin in the areas where the artery is proximal to the skin. Thus, the heart rate is measured using an algorithm. PPG technology can be used in physical sensors, smart watches, or even phone apps to measure heart rate [5]. The application of PPG technology in heart rate monitoring has made significant progress in recent years, especially in the fields of wearable devices, telemedicine, and health monitoring. The market products that utilize PPG for heart rate monitoring, as mentioned above, exemplify this progress.

4. PPG signal characteristics and processing algorithms

4.1. PPG signal format and characteristics

Photoplethysmography (PPG) signals are typical time series physiological signals. Their data are usually stored in the format of time-amplitude pairs. To ensure the capture of pulse - wave details, the sampling rate generally ranges from 100 Hz to 1000 Hz. As depicted in Figure 1, the PPG signal consists of pulsatile (AC) and superimposed (DC) components. The AC component mirrors the periodic light - absorption changes induced by heartbeats, while the DC component represents the constant tissue light absorption, which is associated with the mean blood volume. The AC component results from the cardiac - synchronous blood - volume variations generated by heartbeats, and the DC component can be influenced by respiration, sympathetic nervous system activity, and thermoregulation [5]. The PPG waveform has a typical pulse morphology, including a rapidly rising systolic period, a peak, a slowly falling diastolic period, and a trough. Its morphology is affected by vascular compliance, hemodynamics, and external factors (such as ambient light interference and motion artifacts). In addition, different measurement sites (such as fingertips, earlobes, and wrists) may cause waveform differences, affecting signal amplitude and stability. Therefore, in data processing, preprocessing steps such as filtering, normalization, and baseline drift correction are often required to improve signal quality and the reliability of subsequent analysis [6].

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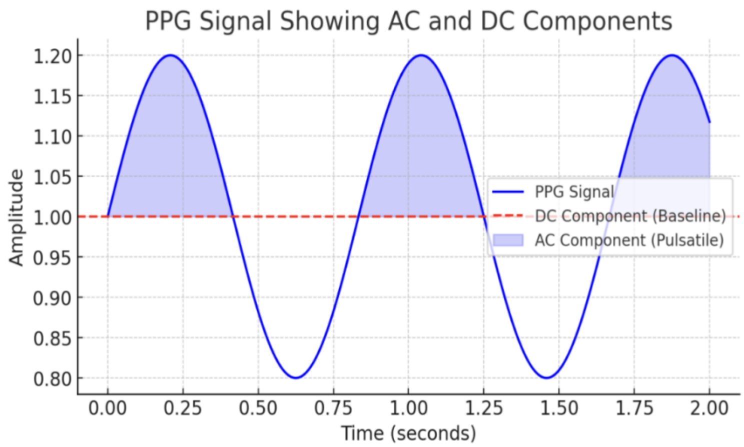

Figure 1 : PPG Singal Showing AC and DC Components

4.2. PPG signal processing algorithm

There are many algorithms for processing PPG signals. This article mainly analyzes four typical algorithms: filtering algorithm, signal early removal algorithm, heart rate detection algorithm and machine learning algorithm.

4.2.1. Filtering Algorithms

PPG signals are often affected by noise, such as motion artifacts and ambient light fluctuations. Filtering, such as wavelet transform, is a common method for noise elimination. This algorithm uses multi-resolution capabilities to eliminate motion artifacts and high-frequency noise. The wavelet decomposition process scales and transforms the mother wavelet, generating new wavelets to fit the original signal. However, wavelet transform has limitations, such as suppressing motion artifacts if they overlap with pulse wave frequency [7].

4.2.2. Denoising Algorithms

Denoising algorithms are primarily utilized to enhance signal quality and eliminate irrelevant signal components. Independent Component Analysis (ICA) is used to separate useful signals and noise signals from multi-channel PPG signals. There is a new method which combines the constrained independent component analysis (cICA) algorithm and adaptive filter to remove motion artifacts (MA) component from the MA contaminated PPG signals with the amplitude information reserved. The new algorithm has successfully addressed the permutation and scale ambiguity problems of conventional ICA. As a result, this algorithm could be used in the situations where one wants to extract the interested source automatically from the mixed observed signals with the amplitude information reserved. The results of this study demonstrated the effectiveness of this proposed method. The research results prove the effectiveness of this method [8].

4.2.3. Heart Rate Detection Algorithms

Heart rate extraction is crucial in PPG signal processing. Researchers have developed a new peak detection algorithm called the adaptive segmentation method (ASM) to estimate heart rate variability (HRV) by finding the peak value in PPG signals. HRV is calculated by measuring the time intervals between peak values in the PPG signal. ASM separates PPG signals into segments with sample sizes and compares peak points with maximum points in these segments. Experimental results show that ASM can be used for HRV estimation and detecting peaks from raw and noisy PPG signals without a pre-processing method [9].

4.2.4. Machine Learning Algorithms

With the burgeoning development of artificial intelligence technology, an increasing number of machine learning algorithms are used to process PPG signals. Among them, the Convolutional Neural Network (CNN) has emerged as a powerful tool. CNN is employed to automatically extract features from PPG signals for heart rate monitoring purposes. Two-dimensional (2-D) image data result in a much more powerful information representation, so several authors have considered transforming the one-dimensional PPG time series into images to exploit the current advantages of CNNs. The resulting matrix was used as the input of a 2-D CNN classifier with ReLU as the activation function, thus achieving an accuracy of 96.6% and 94.6% for local and publicly available datasets. CNN reduces the computational complexity and enables real-time classification. Therefore, it is feasible to expect that CNNs utilizing 1-D signals directly can achieve a classification performance comparable to 2-D CNNs [10].

5. Interaction and application scenarios of AI and PPG core-sheath integration

AI deep learning models can improve the reliability of PPG sensing systems by denoising and filtering out artifacts, enhancing key heart rate signals, and adjusting algorithms based on individual physiological characteristics. This can be applied to newborn heart rate monitoring, detecting conditions early and transmitting them to parents or medical systems for real-time analysis.

6. Demand for infant clothing with heart rate monitoring function

6.1. User demand and market demand

Sudden Infant Death Syndrome (SUID) is a serious health issue affecting children under one year old, with around 3,700 cases reported in the US in 2022 [11]. The neonatal period is particularly vulnerable, and high-quality delivery and neonatal care are crucial [12, 13]. Infant clothing with real-time heart rate monitoring and AI analysis can help parents monitor their babies' health, especially for premature babies. However, traditional sensors may cause discomfort and data loss.

6.2. Importance for infants and young children

According to surveys, the heart rate of infants is 110-130 beats/min, that of toddlers is 100-120 beats/min, that of preschoolers is 80-100 beats/min, and that of school-age children is 70-90 beats/min [14]. Before sudden death, infants usually experience a gradual decrease in heart rate (bradycardia), a decrease in heart rate variability (HRV), or even a sudden drop in heart rate. Studies have found that infants at high risk of SIDS have lower HRV, especially during sleep, when the autonomic nervous system cannot effectively regulate heart rate. Therefore, comfortable infant clothing with heart rate monitoring plays an important role in monitoring the health status of infants and young children and in unexpected interventions.

7. Conclusion

Smart clothing represents a burgeoning trend for the future and can continuously meet people's pursuit of high-quality life. However, at present, such products generally have the problem of unavoidable signal interference. Therefore, it is necessary to strengthen AI's processing of noise and artifacts to keep the system updated and iterated. More experiments are still needed to improve signal processing technology. On another front, considering the softness and skin - friendliness requisites of infant clothing, the integration of PPG sensors with core - sheath structures still demands careful consideration regarding comfort, and the assembly technology needs to be incessantly optimized. Once the needs of infant clothing can be adequately met, it is conceivable that, in the future scenarios, PPG and core sheath integrated clothing can be expanded to the fields of men's and women's clothing, combining fashion and popular trends to design ready-made clothes that are popular with the public and have health monitoring, fashion, and practicality. However, this article has limitations such as lack of experimental data and in-depth discussion of the technical details of the core sheath and PPG integration. Further research is still needed to verify its actual effect and commercial feasibility.

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