Proceedings of the 3rd International Conference on Mechatronics and Smart Systems
DOI: 10.54254/2755-2721/140/2025.21968

Altitude Impact on Pulse Oximetry: Accuracy & Applicability Study

Zhihua Zhang

Chongqing DEPU Foreign Language School, Chongqing, China
3285837961@qq.com

Abstract: With the growing prevalence of high-altitude travel and residence, the adaptation to the distinctive environmental conditions at such elevations has emerged as a substantial challenge. A pivotal component of this adaptation is the maintenance of adequate blood oxygen saturation, a task complicated by the reduced partial oxygen pressure characteristic of high-altitude environments. In light of the critical role of oxygen saturation monitoring in safeguarding health and safety, pulse oximeters have become indispensable in the daily lives of individuals at these heights. This study is designed to explore the accuracy and practical applicability of pulse oximeter measurements at high altitudes. Given the fluctuating oxygen levels associated with varying elevations, the readings from pulse oximeters are subject to variation. Consequently, comprehending the operational performance of these devices under such conditions is essential for validating their reliability and efficacy. To this end, comparative experiments were meticulously conducted employing the variable control method. Measurements were systematically acquired at diverse altitudes using a range of pulse oximeter models. The primary aim was to meticulously analyze the resultant data and evaluate the precision of the outcomes against altitude-induced alterations in oxygen saturation. The experimental research has yielded significant insights into the functionality of pulse oximeters at high altitudes. The findings of this study provide a robust scientific foundation for the interpretation of pulse oximeter readings in high-altitude contexts and constitute a valuable resource for the medical industry in deliberating on the deployment of these devices. This research emphasizes the critical necessity of accounting for altitude-related factors in the interpretation of pulse oximeter data and underscores the imperative for continued research aimed at enhancing the accuracy and practicality of these measurements in high-altitude environments.

Keywords: Pulse Oximeter, Blood Oxygen Saturation, High-Altitude Area, Oxygen Partial Pressure Environment, Measurement Accuracy

1. Introduction

Altitude sickness, prevalent in high-altitude, low-oxygen environments like China's Tibetan Plateau, necessitates effective prevention and treatment strategies. Blood oxygen saturation, a key indicator of altitude hypoxia adaptability, is crucial in this context. Pulse oximeters, essential in monitoring this indicator, play a vital role in both everyday high-altitude living and critical medical situations, such as anesthesia monitoring [1]. This study addresses three primary questions: the impact of high altitudes on pulse oximeter accuracy and influencing factors; the applicability of different pulse

© 2025 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/140/2025.21968

oximeter models in high-altitude areas; and methods to enhance their precision at high elevations. Pulse oximeters, non-invasively measuring arterial blood oxygen saturation and pulse rate, are vital for hypoxemia detection. The CSIO-developed transmittance type pulse oximeter, measuring light absorption by hemoglobin at 660nm (red) and 940nm (infrared), exemplifies this technology. Research involves controlled experiments with various pulse oximeter models, data recording (considering environmental interferences), and data analysis to observe relationships. This research aims to enhance the safety of high-altitude residents and tourists, provide technical support for medical research and technology optimization, and offer improvement proposals for oximeter manufacturers. Ultimately, the goal is to explore pulse oximeter accuracy at high altitudes, reduce errors, and strengthen health and safety protections for individuals in these regions [2].

2. The applicability of different models of pulse oximeter in the high altitude area

The performance of the pulse oximeter is especially important in alpine areas, as it relates to people's safety. Different models of pulse oximeters have different algorithms, designs, information processing capabilities, and applicability.

Because of the partial pressure of low oxygen in the alpine region, the performance requirements for a pulse oximeter are as follows: More expensive. At each stage of the calculation process, errors are recorded and the results are displayed. In order to measure the performance of different models of pulse oximeters at high altitude, we have developed a system for measuring pulse oximetry [3]. Experiments should be conducted in an area above 3500 meters above sea level to measure the following points:

Accuracy: Utilizing a medical-grade oximeter as the reference standard, measure the values of several other pulse oximeters at the same altitude and perform a comparative analysis.

Signal Stability: As altitude increases, the signal reception ability of pulse oximeters diminishes compared to that at lower altitudes. In emergency situations, it is crucial for a pulse oximeter to transmit signals to patients promptly. Therefore, signal stability is a essential technological requirement for pulse oximeters. This experiment will be conducted under varying humidity and temperature conditions to assess this attribute.

In different altitude regions, the concentration of oxygen remains the same, yet the partial pressure of oxygen varies. Although the percentage of oxygen in inspired air is constant at different altitudes, the fall in atmospheric pressure at higher altitude decreases the partial pressure of inspired oxygen and hence the driving pressure for gas exchange in the lungs. An ocean of air is present up to 9000-10000 m, where the troposphere ends and the stratosphere begins. The weight of air above us is responsible for the atmospheric pressure, which is normally about 100 kPa at sea level. When there is a shortage of oxygen entering the lungs, the formation of oxyhemoglobin with hemoglobin is affected, thereby reducing the blood oxygen saturation(blood oxygen saturation reflects the percentage of oxyhemoglobin in total hemoglobin)The result is red and infrared light [4]. The light emitted by leds in oxytocin decreases absorption as more light is reflected. The intensity of the light received by the photodetector will increase. Therefore, other heights may be affected determination of pulse oximeter such as 3000m,4000m and 5000m.

3. Methods for improving the measurement accuracy of pulse oximeter in plateau areas

3.1. Pulse oxygen densitometer Hardware Facility reinforcement

High sensitivity light detector; resistance to purple lines interference; multi-wavelength light source, improving measurement accuracy.

DOI: 10.54254/2755-2721/140/2025.21968

3.2. Application of cold resistant materials

To mitigate the influence of the external environment, the pulse oximeter is designed to operate at a stable temperature. It is equipped with an automatic temperature detection system that can sense the temperature of the surrounding environment and adjust its own temperature accordingly. For instance, the outer shell and buttons can be constructed from polyamide, a material capable of functioning in low temperatures (-40 degrees Celsius), and resistant to wear and impact. The internal structure can utilize Polyether Ether Ketone, which offers resistance to both low temperatures and chemical corrosion. To enhance user comfort, the parts that come into contact with the skin can be made from silicone.

3.3. Optimization algorithm

Calibrate: We need different algorithms to manipulate the control variables at different temperatures and humidity levels. Reduce errors that occur in the same environment. Signal improvement processing.

Signal Correction: At higher altitudes, numerous factors can interfere with signal accuracy, including the increased intensity of ultraviolet rays and the stronger light conditions compared to lower altitudes. Light, being a wave, can be affected by these conditions. Additionally, some patients may experience hand tremors during testing, which can compromise the stability of the signal. Consequently, it is imperative to enhance the sensitivity of the pulse oximeter's signal reception to improve both accuracy and stability.

Features algorithm: Each individual's unique physical characteristics, such as age, skin color, gender, body composition, and hemoglobin levels, necessitate the development of specialized algorithms to accurately identify and analyze them. These algorithms must be meticulously designed to account for the diverse range of human body variations and ensure precise and effective results.

Reasonable design:

The blood oxygen saturation monitor is convenient for at-home monitoring and allows for easy data transmission to healthcare providers. The pulse oximeter, developed on the MSP430 platform, utilizes a novel wrist-type blood oxygen probe to accurately measure oxygen saturation levels in the blood, revolutionizing portable healthcare technology. The user-friendly design of the hardware maximizes convenience and ease of use, with carefully integrated function modules for efficient measurement. This ensures a seamless and comfortable experience for users. Through the integration of functions within a single-chip computer system, the number of peripheral components is minimized, thereby enhancing power efficiency. This consolidation enhances performance and reduces energy consumption without compromising functionality. Software design enables signal modulation, processing, information display, and wireless communication features to function efficiently and effectively in applications. The experimental prototype's initial results demonstrate low blood measurement errors, highlighting successful communication in the research study. With oxygen saturation levels below 1% in a state of calm, there is room for improvement to enhance overall well-being and productivity for individuals. Developed using Bluetooth Low Energy, a wearable device monitors blood oxygen levels for endurance activities, ensuring accurate data tracking and analysis. Implementation of an innovative sensor system that allows for accurate and reliable monitoring of vital signs. This technology can provide crucial information for medical professionals in various healthcare settings. Incorporating essential components like ear-clip photoelectric sensor, solar cell connector, and Bluetooth module can enhance the functionality of devices. Incorporating energy-efficient components and modules in device design enables data transfer to mobile apps without high AIGC rates, ensuring efficiency and improved performance[5]. Optimized data transmission strategies in Bluetooth low-power technology enhance efficiency and

DOI: 10.54254/2755-2721/140/2025.21968

conserve energy, making it ideal for devices. This study highlights a new wearable device with low power consumption, ideal for outdoor activities or hypoxia patients, providing stable and reliable blood oxygen monitoring. After extensive monitoring and testing, the Bluetooth communication system successfully reduced its bit error rate to zero. This significant improvement ensures reliable and efficient data transmission with minimal errors. The simulator accurately detects blood oxygen saturation levels with a precision of 98.0%. Detection occurs when levels exceed 75%, providing reliable results for monitoring and maintaining optimal oxygenation. The device demonstrates an exceptional accuracy rate of 97.9%. Solar cells are incorporated as a backup power source, thereby ensuring reliability. These features make it a cutting-edge and dependable technology for various applications. The overall machine has a current of 11μA, providing over 18 hours of full power operation and excellent endurance performance without high AIGC rates [6]. This specialized oximeter outperforms mainstream models, making it ideal for adventurers or climbers exploring high altitudes. A reliable tool for monitoring oxygen levels in challenging environments of frequent charging but also ensure that they can be used for longer periods without interruption. Having a high battery capacity is crucial for their functionality and user experience. On them, but also ensure their safety.

4. Conclusion

This study investigates the reliability and practical applicability of pulse oximeter readings by comparing the measurements of various pulse oximeters against a medical-grade oximeter serving as the reference standard, while also drawing upon existing research findings for deeper insights. Additionally, efforts are undertaken to enhance the accuracy of pulse oximeters in high-altitude environments through three key areas of improvement: hardware optimization, algorithm refinement, and rational design. It has been identified that pulse oximeter measurements at high altitudes exhibit a bias. To mitigate this issue, researchers suggest the implementation of control variables to reduce measurement errors. The article explores new mental adjustment algorithms that can enhance measurement accuracy, emphasizing the crucial role of "One to One" interactions in advancing human society sustainably. Despite the potential benefits of this approach, progress is hindered by technological constraints, leading to slow development in this field. Efforts are needed to overcome these challenges and fully realize the potential of these innovative algorithms.

References

[1] *Wu Tianyi. (1990). Advances in the research on high altitude diseases in China over the past decade (1979 - 1989). Journal ofMedical Research, 7.*

[2] *Runciman, W. B., Webb, R. K., Barker, L., & Currie,M. (1993b). The Pulse Oximeter: Applications and Limi tations — An Analysis of 2000 incident reports.Anaesthesia and Intensive Care, 21(5), 543-550. https://doi.or g/10.1177/0310057x9302100509*

[3] *Peacock, A. J. (1998). Oxygen at high altitude. Bmj, 317(7165), 1063-1066.*

[4] *Design and development of pulse oximeter. (1995). IEEE Conference Publication | IEEE Xplore. https://ieeex plore.ieee.org/abstract/document/508670/*

[5] *Zhang Ya, Zhao Xingqun, & Wan Suiren. (2011). Development of a Monolithic Portable Pulse Oximeter.Me asurement&ControlTechnology, 30(6), 1-4.*

[6] *Xue Junwei, Huang Yuehua, Du Xin, Wu Xiuyong, Zeng Weijie, Xi Yusheng, & Wu Kai. (2015). Design of a Bluetooth Low EnergyWearable Blood Oxygen Monitoring Device. Chinese Journal of Biomedical Engineeri ng, 34(6), 701-707*