Proceedings of the 5th International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/122/2025.19602

Application of Optical Sensing Technology in Oximeter

Jiuyue Ma[1,a,*]

[1]*School of Science, Yanbian University, Yanji City, Jilin Province, 133000, China*
a. jy.ma.phy@gmail.com
**corresponding author*

Abstract: Optical sensing technology now plays an important role in the field of health monitoring. With the improvement of the level of science and technology and the rapid development of the medical service industry, people pay more and more attention to health, resulting in the various functions of the oximeter are becoming more and more perfect, and the oximeter has been more popular with people since then. This paper mainly studies the application of optical sensing technology in oximeters, especially the importance of health monitoring. The purpose of this article is to review the historical development of optical sensors, discuss the technological innovation of oximeters, compare different technical performance indicators, and some practical application scenarios of oximeters. This paper will conduct research and analysis through a review method, and find that optical sensing technology has significantly improved the accuracy of oximeter measurement, and optical sensing technology will continue to develop and benefit mankind in the future.

Keywords: Optical sensing technology, Oximeter, Health monitoring.

1. Introduction

Optical sensing technology is a technology that converts optical signals into electrical signals through the photoelectric effect, which can be used to detect many physical parameters. Because there is no electromagnetic interference, and there is no interference between optical signals, the transmission is controllable, so the optical technology has the characteristics of high precision [1]. With the development of optical sensing technology and the advancement of medical devices, optical sensing technology has been gradually applied to the field of oximeter, so more and more people are concerned about oximeter and physical health. Optical sensing technology has gradually made many breakthroughs, especially in clinical diagnosis and treatment, which has brought many conveniences to people. Traditional optical sensors use the characteristics of visible light to assess the content of oxygen in the blood, and the accuracy of measurement still needs to be investigated, even though the current optical sensing technology has made a lot of technical progress and breakthroughs, it still needs to be explored in the next step in improving the accuracy of measurement and reducing measurement errors, which is also a research gap that has always existed today. This paper will focus on the application of optical sensing technology in oximeters, discuss the technological innovation of oximeters, and compare different technical performance indicators. This article will further analyze the importance of optical sensing technology through a review approach to promote the development of optical sensing technology and the field of personalized medicine today.

© 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: 10.54254/2755-2721/122/2025.19602

2. Historical development of application of optical sensing technology in oximeters

2.1. Historical background of optical sensing technology

The invention of the pulse oximeter and the advancement of optical sensing technology have largely contributed to the modern medical system. Japan engineer Takuo Aoyagi has greatly advanced the progress of optical sensing technology and oximeters, and found that by measuring the change in light absorption of arterial blood as the heart beats, blood oxygen saturation can be accurately calculated. Aoyagi proposed the use of the absorbance characteristics of oxidized heme and reduced heme to determine the oxygen saturation of the blood, the light first passes through the pure tissue, and then through the blood, using the transmitted light before and after ischemia to find the absorbance of the blood in the tissue, which is called the ischemic method [2]. This operation of Aoyagi played a very important role at the time, and it effectively promoted the development of early oximeters.

With the development of science and technology and the improvement of the medical level, oximeter and optical sensing technology have gradually improved. Conventional optical sensors still have to solve a number of problems, such as ambient light interference and motion artifacts, and the measured data can still be incorrect. With continuous research and investigation, new research results have been gradually obtained in high-sensitivity detectors and multi-wavelength light sources, which have solved the problems of partial measurement errors and measurement accuracy to a certain extent, making the measurement data more accurate and more effective in suppressing the influence of motion artifacts. Nowadays, the functionality of oximeters is increasing and becoming more and more intelligent, which provides great convenience for health monitoring systems and telemedicine.

2.2. Key technical progress

Traditional optical sensors use the principle of light sensing to detect the physical or chemical phenomena of changes in human skin through different wavelengths of light, such as red and infrared light signals. Early pulse oximeters calculated oxygen saturation on this basis.

With the rapid progress of science and technology in recent years, traditional optical sensors can no longer cope with the accuracy of measurement and clinical supply, and most of these early optical sensors use a single wavelength light source, which shows a series of limitations in some performance parameters in terms of sensitivity, response time, dynamic range, etc. With continuous research, multi-wavelength light source technology, that is, the use of multi-wavelength light source to cope with measurement errors, has begun to gradually develop and apply. The AvaSpec-HS1024x58TEC high-sensitivity fiber spectrometer was used to quickly collect pulse wave spectral data, and the absorbance information of each wavelength of light was extracted based on the principle of dynamic spectroscopy, and multiple spectral information was added to the calculation of blood oxygen saturation value, making full use of the spectral information of different bands to reduce the measurement error of blood oxygen saturation [3].To a certain extent, this technology has contributed to the development of oximeters and modern medicine. For example, pulse oximeters combine red and infrared light to reduce the impact of errors, and visible multi-wavelength technology can make the measurement data more accurate and can effectively improve errors.

2.3. Technological innovations in the development of oximeters

The pulse oximeter invented by Japanese engineer Takuo Aoyagi using non-invasive optical technology is the earliest breakthrough of the oximeter, that is, the blood oxygen saturation of the human body can be measured without drawing blood. Using light from different wavelengths of light sources and using the principle of light induction, blood oxygen saturation can be calculated more

DOI: 10.54254/2755-2721/122/2025.19602

accurately. Aoyagi's technology laid the foundation for the early development of oximeters and was a key turning point in the development of oximeters.

Traditional optical sensors mostly use only red and infrared light. However, under certain conditions, such as ambient light interference, skin pigmentation, etc. There are still errors in the measurement data. Nowadays, with the progress of science and technology and the development of medicine, multi-wavelength light source technology has begun to develop, that is, to combine more and more complex multi-wavelength light sources to measure human blood oxygen levels, effectively distinguish different types of hemoglobin, so as to reduce the measurement error caused by certain factors and improve the measurement accuracy in a certain degree of a complex environment.

With the advancement of some technologies such as microelectronics and microelectromechanical systems, the form of oximeter has been significantly improved and breakthrough. It has evolved from an early large-scale desktop device to today's miniaturized, intelligent, wearable, and convenient device, and has achieved miniaturization and integration in design. For example, today's smartwatches integrate biometric monitoring and add integrated technology to make it more convenient for people to use.

In addition to the above technologies, modern oximeters also have more technologies and innovations. Near-infrared spectroscopy is used to detect tissue blood oxygen, and the main algorithm is based on Lambert-Beale law. Due to the difference in the absorbance of near-infrared light at the wavelength of 600~900 nm between water, deoxygenated hemoglobin and oxygenated hemoglobin in the human body, the amount of deoxygenated hemoglobin and oxygenated hemoglobin in the blood and the total hemoglobin amount can be calculated by using this characteristic [4]. These technologies greatly enable high-sensitivity measurements, remote monitoring, and long-distance wireless transmission, making measurement data more accurate. In the future, the technology of oximeter will continue to break through and improve, and integrate with more technologies.

3. Application status of optical sensing technology in blood oxygen monitoring

3.1. Sensor types and applications

With the advancement of modern technology, the types of optical sensors are becoming more and more abundant. Photodiode is one of the common optical sensors, which uses the difference between red or infrared light absorbed by oxygenated hemoglobin and non-oxygenated hemoglobin in the blood after passing through human skin, and converts the light signal into an electrical signal to monitor the change of blood oxygen level and light intensity. Photodiodes have very excellent use characteristics, such as fast responsiveness, high sensitivity, etc., which provide convenience for patients with chronic diseases, can achieve real-time monitoring, and are currently commonly used optical sensor devices.

Fiber optic sensors are also one of the most common optical sensors at present. Compared with traditional sensors, fiber optic sensors can be used under harsh conditions such as strong electromagnetic interference, high temperature and high pressure, atomic radiation, explosiveness, and chemical corrosion, and the advantages of high sensitivity and low loss make the fiber optic sensors widely used [5]. Optical fiber sensors transmit optical signals through optical fibers, which have strong anti-interference capabilities and are capable of long-distance transmission. The optical fiber sensor will not be interfered by complex environments, etc., and can better achieve high-precision measurement and effectively avoid measurement errors. Fiber optic sensors are suitable for telemedicine devices and can be monitored remotely, providing great convenience for patients who are unable to travel.

The multi-wavelength optical sensor uses multiple light sources of different wavelengths to measure the blood oxygen level of the human body, which reduces the error effect caused by

DOI: 10.54254/2755-2721/122/2025.19602

environmental light interference, motion artifacts, skin pigments and other factors, and has strong anti-interference. Compared with conventional optical sensors, this technology effectively reduces error interference and improves measurement accuracy. Multi-wavelength sensors have contributed to the development of medicine and contributed to the development of oximeters. Wearable devices such as smartwatches have also become widespread in recent years, allowing people to monitor continuously and use the sensors for a long time.

3.2. Comparison of technical performance of traditional oximeters and modern oximeters

Traditional oximeters use red and infrared light to pass through human skin, and use oxygenated hemoglobin and reduced hemoglobin to absorb different wavelengths of light to measure blood oxygen levels. However, these traditional optical sensors still have a series of room for improvement when using only these two wavelengths of light sources, and when the human body is moving or in some complex environments, these traditional optical sensors will be susceptible to noise interference, resulting in a certain error in the measured data. Multi-wavelength light source sensors can improve accuracy by providing more data than traditional oximeters. The multi-wavelength pulse oximeter was compared with the traditional dual-wavelength pulse oximeter, and it was found that the multi-wavelength pulse oximeter was more stable in anti-motion interference through the comparison of the two sets of data [6]. Therefore, multi-wavelength sensors can make the measurement data more accurate. It can be seen that although red light and infrared light are the common wavelengths of traditional oximeters, the applicability of multi-wavelength technology is relatively superior.

3.3. Practical application scenarios of modern oximeters

In recent years, pulse oximeters have been widely used in various scenarios. In the modern medical field, the oximeter has become an important instrument for medical monitoring, which can monitor the blood oxygen level of patients in real time and for a long time. Especially for patients with cardiovascular and cerebrovascular diseases and respiratory diseases, the oximeter can continuously monitor the blood oxygen content of the patient, timely prevent hypoxia or oxygen deficiency causing dyspnea, greatly reduce the probability of onset, and play a role in health prediction. During anesthesia surgery and post-operative recovery, blood oxygen monitoring is also an essential step to ensure the safety of vital signs.

In addition, wearable oximeters can also be used to monitor the physical indicators of patients with chronic diseases, especially for those with limited mobility, so that such patients can keep track of their personal physical health status and prevent the recurrence of diseases. For the elderly, pregnant women and other people, wearable oximeters can help such people record blood oxygen saturation at any time to ensure good health and prevent diseases. In addition, wearable oximeters can also be used to monitor sleep quality, so as to understand the sleep quality and make improvements and adjustments.

4. Challenges and limitations of modern oximeter technology

Traditional oximeters use red and infrared light to measure blood oxygen saturation through the skin, but there are still factors such as dark skin pigment or thick tissues that affect the accuracy of the measurement. Even though multi-wavelength techniques are the most effective way to mitigate and avoid some errors, the effects of skin pigment and tissue thickness still show some limitations.

When the human body is moving, the activity of the human body will cause interference with the light signal, resulting in motion artifacts, and strong light interference such as sunlight will also affect the light signal of the oximeter. Motion artifacts and ambient light interference can have an impact on the measurement results and cause measurement errors. While some devices now introduce motion

DOI: 10.54254/2755-2721/122/2025.19602

compensation algorithms to eliminate these effects, the results are not significant. Therefore, eliminating motion artifacts and errors caused by ambient light interference is still an important challenge.

Irritable patients have inaccurate readings due to probe movement or detachment, and the probe is easily damaged, and the probe clamp is too tight and can also affect circulation. If the outside light is too strong, avoid light, otherwise, the accuracy of the values will be affected [7]. Therefore, especially in complex environments or some extreme situations, the accuracy of oximeters often shows certain limitations, and how to improve the accuracy of oximeters has always been a major technical challenge.

5. Conclusion

This paper mainly discusses the application of optical sensing technology in oximeters and the technological innovation of oximeters, reviews the historical development of optical sensors, compares different technical performance indicators, and some practical application scenarios of oximeters. In this paper, it is found that optical sensing technology has significantly improved the accuracy of oximeter measurement, and the application scenarios are very wide. The research methods in this paper are mainly review and analysis and have not been discussed in depth in data processing and algorithm optimization, and the above contents will continue to be discussed and analyzed in the future. Future research may focus on improving sensor accuracy, improving the design of light sources and photodetectors, combining artificial intelligence and big data analysis to make oximeters more intelligent, and technology integration to integrate oximeters with more physiological parameters to form a multi-parameter health monitoring system.

References

[1] *Qin Chen, Xianghong Nan, Wenyue Liang, et al. Research Progress of On-chip Integrated Optical Sensing Detection Technology (Invited)[J]. Infrared and Laser, 2022, 51(01): 360-377.*

[2] *Takuo Aoyagi. The birth of the pulse oximeter and its theory[J]. The Journal of Japan Society for Clinical Anesthesia, 1990, 10(1): 1-11.*

[3] *Xiaofei Wang, Wenjun Zhao. Multi-wavelength pulse oximetry measurement based on dynamic spectroscopy[J]. Spectroscopy and Spectral, 2014(5): 1323-1326.*

[4] *Ming Lu, Bo Liu, Xin Zhang, et al. Development and development of wireless portable tissue oximeter[J]. China Medical Devices, 2022, 37(6): 64-67.*

[5] *Huiling He, Chunmei Zhao, Dan Chen, et al. The current state of fiber optic sensors[J]. Laser & Optoelectronics, 2004, 41(3): 39-41,38.*

[6] *Xiaohua Yu. Research on measurement methods based on multi-wavelength pulse oximetry[D]. Hebei: Yanshan University, 2018.*

[7] *Shuzhen Lu. Use and experience of pulse oximetry[J]. The Medical Forum, 2009,13(12): 384.*