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Wearable NIRS device for malaria detection

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ABSTRACT

Malaria remains a serious health problem globally, causing millions of cases and many deaths each year. For example, in 2023, malaria spread to 263 million people and killed 597,000 of them globally. Detecting the disease early is very important because it helps doctors decide on the right treatment to save lives and stop the further spread of the illness. However, most current tests require a blood sample, which can be painful, expensive, and difficult in remote areas. Here I suggest a new, non-invasive method that uses a wearable near infrared spectroscopy (NIRS) device which uses near-infrared light to check for signs of malaria in the blood. The device continuously monitors blood properties and uses simple computer programs to look for patterns that indicate malarial infection. It sends the data wirelessly in real time to a phone or computer, which makes it possible to start treatment quickly and reduce the risk of serious illness. This easier and less expensive approach could work well in places with few medical facilities, helping to catch malaria early and treat it faster, which may lead to fewer severe cases and lower death rates.

Keywords*:* *malaria*, *NIRS*, *wearable*, *healthcare*, *early detection*, *wireless*, *AI*, *non-invasive*, *low-resource diagnostics*

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INTRODUCTION

Malaria remains a significant global health concern, with the World Health Organization estimating that approximately 263 million cases occur each year, causing nearly 597,000 deaths (World Health Organization [WHO], 2025). The disease is caused by *Plasmodium* parasites transmitted through infected mosquito bites, and common symptoms include fever, chills, headache, and muscle pain, while severe cases may involve respiratory distress and organ failure. Although malaria occurs in many regions, sub-Saharan Africa is hit hardest, with around 94% of cases recorded there (WHO, 2025). Early detection is crucial because prompt treatment can dramatically reduce mortality; studies show that early intervention may lower the risk of death by up to 90% (Centers for Disease Control and Prevention [CDC], 2024). However, current diagnostic methods often require invasive blood tests that are time-consuming and difficult to perform in resource-poor settings. This underscores the need for more accessible and less invasive diagnostic methods, especially in high-prevalence regions.

The current landscape of malaria control and prevention efforts relies heavily on vector control measures such as insecticide-treated bed nets and indoor residual spraying (WHO, 2025). While these interventions help reduce transmission, they do not eliminate the disease entirely. Malaria continues to be a major public health challenge, particularly in areas with limited access to healthcare facilities (WHO, 2025). Socioeconomic factors also play a role in the persistence of malaria, as impoverished communities often lack the resources to implement effective prevention and treatment strategies. Climate change further complicates malaria control efforts by altering mosquito breeding patterns and expanding the geographical range of transmission (WHO, 2025). As malaria remains endemic in many parts of the world, the development of innovative and accessible diagnostic tools is crucial to strengthening global efforts to combat the disease.

CURRENT DETECTION METHODS

Malaria is traditionally diagnosed through microscopy, where blood smears are prepared and examined under a microscope to detect the presence of parasites (Fig. 1). This technique is considered the gold standard because it provides immediate information about the presence, density, and species of malaria parasites. However, it relies on trained technicians and laboratory infrastructure, which can be scarce in remote regions (CDC, 2024). Polymerase chain reaction (PCR) testing, which amplifies parasitic DNA, offers highly accurate results and is useful for confirming species and detecting mixed infections, but it requires specialized equipment and is not ideal for acute diagnosis (CDC, 2024). Another widely used method is the rapid diagnostic test (RDT), which detects malaria-specific antigens in the blood. RDTs provide results within minutes and serve as an alternative in places without microscopy. However, they have limitations, such as the inability to quantify parasitemia, the persistence of positive results after treatment, and the potential for false negatives due to mutations in malaria parasites (CDC, 2024). Despite the effectiveness of these methods, the reliance on blood samples, laboratory infrastructure, and trained personnel poses challenges for widespread, early detection in many regions.

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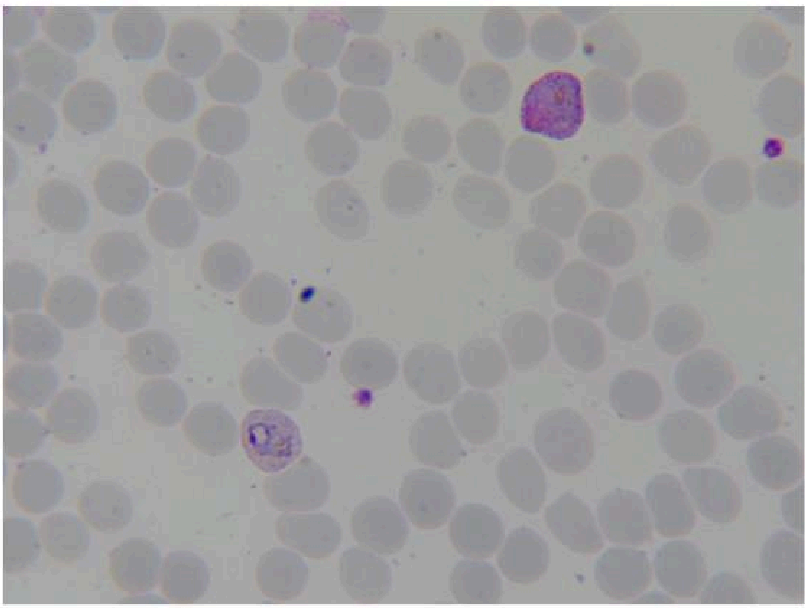
Figure 1
Malaria blood smears



Note. *From "Computer vision for microscopy diagnosis of malaria," by Tek et al., 2009, Malaria Journal, 8, p. 153 (https://doi.org/10.1186/1475-2875-8-153).*

Researchers have begun exploring more advanced techniques that could potentially reduce or eliminate the need for drawing blood. Though promising, these techniques often require highly sensitive and expensive equipment, making them less suitable for resource-limited environments. The need for a simple, robust, and cost-effective diagnostic tool remains a key challenge. A non-invasive and continuous monitoring system could help overcome many of these obstacles by providing real-time data without the need for laboratory facilities. Such an approach would be particularly beneficial in rural clinics or mobile health initiatives, where access to trained personnel and medical infrastructure is limited. Unlike traditional blood tests that offer only a single snapshot of a patient's health, continuous monitoring could track disease progression and treatment response over time. This capability is especially valuable in settings where frequent medical visits are impractical. By serving as an early-warning system, a continuous monitoring approach could improve treatment outcomes, reduce hospitalizations, and enhance public health strategies aimed at controlling malaria more effectively.

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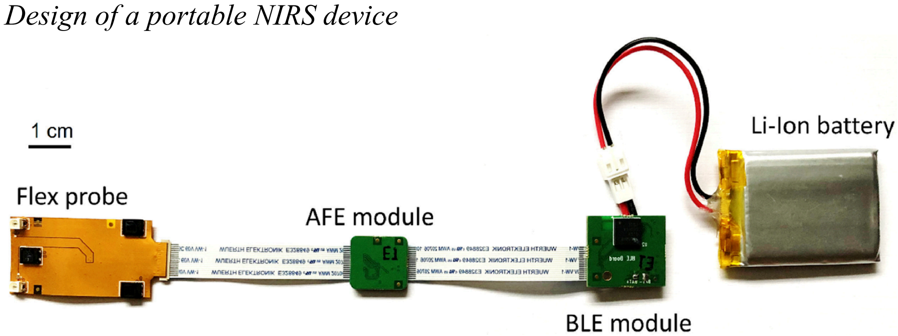
PROPOSED METHODOLOGY

Near infrared spectroscopy (NIRS) is a non-invasive optical technique that measures the absorption and scattering of near-infrared light in biological tissues. It has been widely used in medical diagnostics to assess blood and tissue composition, making it a promising tool for malaria detection. By analyzing changes in blood properties through light interaction, NIRS can provide valuable insights into the presence of malaria infection without requiring a blood sample (Fricke et al., 2018). Additional research supports the use of spectroscopy techniques for malaria detection. Wood et al. (2024) showed how spectroscopic tools can detect malaria-induced changes in blood, even at very low parasite levels. Mwanga et al. (2019) demonstrated that mid-infrared spectroscopy, combined with logistic regression, could detect malaria parasites in dried blood spots. Goh et al. (2025) identified specific visible and near-infrared spectral peaks associated with *Plasmodium falciparum*, further supporting the value of NIRS for detecting malaria-related biomarkers. These studies suggest that non-invasive, light-based methods like NIRS could offer a practical and effective alternative to blood-based diagnostics, especially in field settings with limited resources.

In addition to these findings, Adegoke et al. (2021) developed a portable, matchbox-sized NIRS spectrometer that successfully detected and quantified malaria parasitemia. This proof-of-concept for a compact, low-cost NIRS device demonstrates the feasibility of integrating spectroscopic tools into wearable diagnostic technologies, particularly for use in low-resource environments.

The proposed solution is a wrist-worn device that utilizes NIRS to detect changes in blood cell properties indicative of malaria infection. Near-infrared light is emitted into the wrist, where it interacts with blood vessels. The device collects the light that is reflected or scattered back, and this signal is then processed by an analog front-end (AFE) module, which amplifies and filters the weak optical signals. The processed signals are subsequently digitized and transmitted to a connected system via a Bluetooth Low Energy (BLE) module for further analysis. The design of this prototype device—including the flex probe, AFE module, BLE module, and lithium-ion battery (Fig. 2)—ensures that the device fits comfortably on the wrist while maintaining consistent contact with the skin.

Figure 2
Design of a portable NIRS device



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Note. From "Open-source FlexNIRS: A low-cost, wireless and wearable cerebral health tracker," by Wu et al., 2022, NeuroImage, 256 (https://doi.org/10.1016/j.neuroimage.2022.119216).

NIRS has already shown promise in diagnosing other diseases by analyzing blood and tissue properties. Previous studies have demonstrated the efficacy of NIRS in detecting conditions such as neonatal jaundice and brain injuries (Akikazu Sakudo et al., 2016). NIRS successfully detected cancer and other diseases (Vitorino, R., et al., 2023). Another study explored the application of NIRS in assessing traumatic brain injuries, demonstrating that changes in tissue oxygenation could be accurately measured without invasive procedures. These findings support the feasibility of using NIRS technology for malaria detection, as the method has already been validated for identifying physiological changes in blood composition.

Machine learning algorithms are integral to interpreting the spectral data gathered by the sensor. By training a model on spectral signatures from both healthy and infected individuals, the device can learn to distinguish between characteristic absorption patterns associated with malaria parasites and normal blood cell profiles. NIRS data can be used to classify different parasite stages, showing distinct clusters for ring, schizont, and trophozoite stages (Fig. 3). This stage classification is clinically valuable because different stages can indicate varying degrees of infection severity and help guide treatment decisions. For example, an abundance of ring-stage parasites may suggest an early infection that could be managed with standard treatment protocols, whereas a higher proportion of schizonts might indicate a more advanced infection, necessitating more aggressive or targeted therapy. In a practical scenario, once the device collects data from a user, the model compares the new spectral information against known patterns to predict the likelihood of malaria infection. If the prediction exceeds a certain threshold, the user or healthcare provider is alerted to seek further medical evaluation, and the specific stage information can assist in tailoring the most appropriate treatment plan. These models have been developed and tested using both lab-grown infected red blood cells and live mice infected with malaria. The models achieved up to 96% accuracy in detecting infections at very low parasite levels in lab samples, and up to 94% sensitivity and 86% specificity in live mice studies. These results demonstrate the potential of combining NIRS with machine learning for malaria detection (Sikulu-Lord et al., 2024).

Figure 3
NIRS differentiation of P. falciparum rings, schizonts and trophozoites

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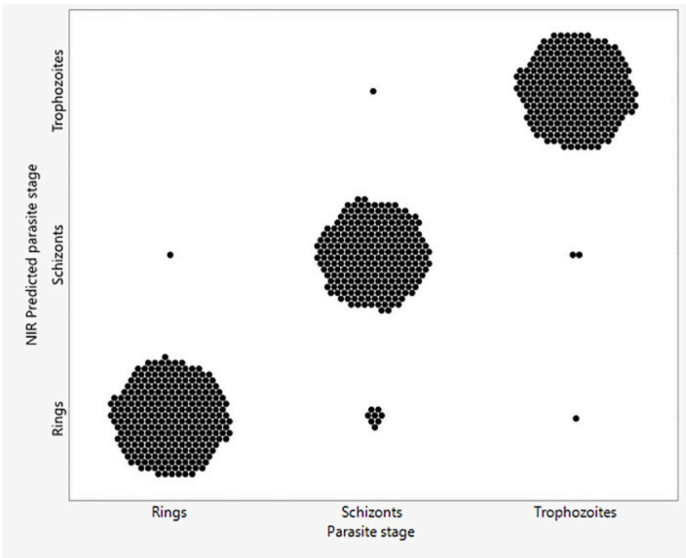

Note. *From "Rapid and non-invasive detection of malaria parasites using near-infrared spectroscopy and machine learning," by Sikulu-Lord et al., 2024, PloS One, 19(3) (https://doi.org/10.1371/journal.pone.0289232).*

Ensuring a wearable device's reliability and durability in harsh environmental conditions—especially in malaria-endemic regions with high humidity, dust, and occasional water exposure—requires careful attention to its Ingress Protection (IP) rating. An IP67 rating is recommended, as it guarantees complete protection against dust ingress and the ability to withstand temporary immersion in water up to 1 meter deep for 30 minutes. To achieve such a rating, the design must integrate sealed enclosures that prevent any ingress, use robust materials that resist corrosion and degradation, and undergo rigorous testing procedures that simulate real-world conditions. These measures help maintain the device's operational integrity even when exposed to challenging environments. By prioritizing these design elements, manufacturers can significantly enhance the device's durability, reduce maintenance costs, and boost user confidence in its performance. In summary, adhering to IP67 standards through thoughtful design, material selection, and comprehensive testing is essential for ensuring reliable operation and long-term durability in environments where dust, moisture, and water are constant challenges.

FUTURE WORK

This proposal is currently at the conceptual stage. No physical prototype has been developed, and the device's design and functionality remain hypothetical. Future work should start with engineering the wearable device into a testable prototype and then large-scale trials to confirm the accuracy of the wearable device in detecting malaria across diverse populations and parasite strains. These studies could include comparisons to gold-standard tests, such as PCR and microscopy, to establish a reliable baseline for performance metrics. Researchers should also investigate whether the device can detect varying parasite loads, including asymptomatic carriers who might otherwise go undiagnosed. Optimizing the machine learning algorithms will be essential to account for individual differences in skin tone, tissue composition, and other biological factors that might influence NIRS measurements.

CONCLUSION

Malaria continues to exact a heavy toll on global health, particularly in resource-limited settings where rapid and reliable diagnosis remains challenging. While existing methods such as microscopy, RDTs, and PCR are effective, they require blood samples and access to laboratory facilities. A wrist-worn NIRS device has the potential to address many of these limitations by providing a non-invasive, portable, and cost-effective diagnostic alternative. If validated, this technology could significantly advance malaria control efforts by facilitating earlier detection and treatment, ultimately reducing morbidity and mortality in regions where the burden of this disease is greatest.

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