Future of Veterinary Point-of-Care Diagnostics through Vis–NIR Spectroscopy

Subjects: Medical Laboratory Technology

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Visible-Near-Infrared (Vis-NIR) spectroscopy is an analytical technology that spans wavelengths from 400 to 2500 nm, enabling rapid, non-invasive, and reagent-free analysis of biological samples. Unlike traditional laboratory methods, Vis-NIR is compatible with portable, miniaturized devices, making it ideal for point-of-care (POC) diagnostics in clinical or field settings. By measuring how light interacts with samples such as blood or feces, the system captures spectral data related to molecular vibrations. When paired with Self-Learning Artificial Intelligence (SLAI) to filter technical interferences, Vis-NIR provides immediate biochemical results from micro-volumes of samples. This technology supports the One Health initiative by decentralizing diagnostics and accelerating clinical decision-making in both human and veterinary medicine.

Vis-NIR spectroscopy | Poin-of-Care (POC) | One Health | Self-Learning AI (SLAI) | Hemogram | Multi-scale interference | Comparative diagnostics | Reagent-free analysis

1. Introduction

Modern medical technology demands high accuracy, rapid results, as the speed of data acquisition is often critical for therapeutic success. Consequently, diagnostics are shifting from centralized laboratories to point-of-care (POC) settings, integrating precision directly into primary or field-based workflows. In veterinary medicine, this shift is particularly vital, as clinicians must rely on objective, real-time physiological data to compensate for animal patients' inability to communicate symptoms [1]. This convergence of human and animal healthcare reflects the One Health framework, fostering multidisciplinary diagnostic innovation [2].

2. Technical Comparison with Other Spectroscopic Methods

Vis-NIR spectroscopy offers a superior balance of portability and analytical capability compared to other established veterinary techniques. Unlike Raman spectroscopy, which is hindered by background fluorescence [3][4], or FTIR, which suffers from strong water interference and bulky hardware [5][6], Vis-NIR is robust and easily miniaturized. Furthermore, while fluorescence spectroscopy often requires invasive probes or chemical labels [7][8], Vis-NIR remains non-invasive and reagent-free [9]. This allows for real-time monitoring of multiple physiological parameters without complex sample preparation, making it the most viable option for routine point-of-care adoption.

3. History and Concept

Vis-NIR spectroscopy is a natural evolution of near-infrared (NIR) spectroscopy. While William Herschel discovered infrared radiation in the 1800s, the analytical value of NIR emerged in 1960 when Karl Norris used it at the USDA for non-destructive moisture measurement in grains. By the late 1970s, it had expanded to forage and animal feed analysis. The integration of the visible spectrum (400–750 nm) led to modern Vis-NIR spectroscopy. Recent advances in fiber optics and LEDs have allowed these instruments to move from specialized labs into the field, where they can now estimate blood parameters in pets without reagents [1].

4. System Architecture and Performance

A typical Vis-NIR spectral detection system consists of a light source, a monochromator, a detector, and optical accessories (Figure 1) [10]. While tungsten-halogen lamps were traditionally used for their wide spectral coverage, they present limitations like excessive heat and short lifespans; consequently, LEDs have emerged as a superior alternative due to their higher efficiency, durability, and lack of radiation burn risk [11]. The interaction between light and sample, via reflectance, transmittance, or interactance, captures spectral information related to molecular vibrations and physical properties [11][12].

In practical POC IoT platforms, this technology is implemented using miniaturized spectrometer modules (e.g., Hamamatsu C12666MA or Ocean Insight STS-vis) and specialized plug-in capsules that require minimal sample volumes (~10 μL) for real-time registration [13]. This approach enables rapid, reagent-free, and decentralized diagnostics by capturing physical and molecular signals at distinctive wavelengths [9][14]. While the hardware captures raw multi-scale interference, the analytical core relies on Self-Learning Artificial Intelligence (SLAI) to unscramble these patterns and provide accurate quantitative parameters [1][13]. This convergence of Vis-NIR spectroscopy and POC testing facilitates rapid clinical decision-making and improves the diagnostic workflow in both human and veterinary medicine [15][16].

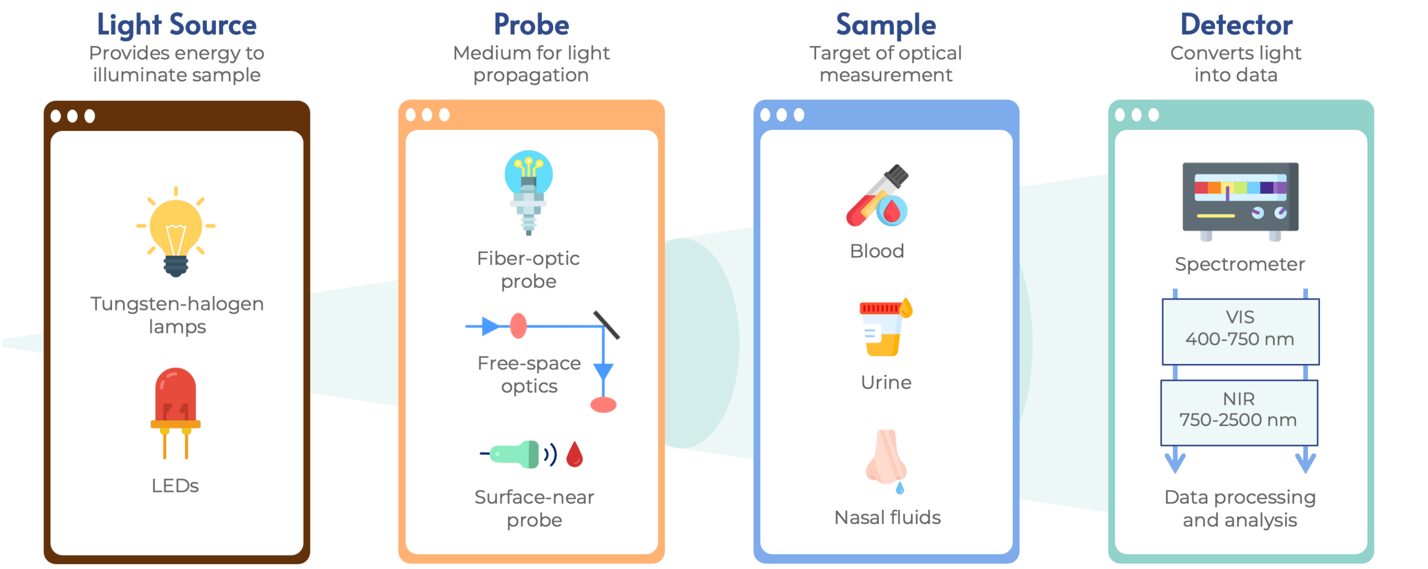

Figure 1. Overview of the Vis-NIR spectroscopy workflow: light emission (LEDs/Tungsten), propagation via probe, sample interaction (transmittance/reflectance), and final detection by the spectrometer.

5. Challenges and Limitations of Vis-NIR Spectroscopy

Despite its potential, Vis-NIR spectroscopy faces physical and analytical challenges, primarily the complex light-sample interactions where scattering effects (Rayleigh and Mie) are often dismissed as noise [1]. Physically, penetration depth is limited to 5–7 mm, and environmental factors like temperature or water absorption can mask critical signals [10][17][18].

Analytically, overlapping spectral bands hinder molecular specificity, particularly in blood, where dominant hemoglobin signals overwhelm less abundant elements, causing deviations from the Beer-Lambert law [1][13][19]. To overcome this, Self-Learning Artificial Intelligence (SLAI) uses covariance mode (CovM) search to transform these interferences into a diagnostic advantage [9][13]. Lastly, while miniaturization enables POC use, it involves constant trade-offs between portability, sensitivity, and cost [10][20].

6. One Health and Comparative Applications

Vis-NIR spectroscopy is a versatile tool with the potential to democratize access to health technologies by transitioning from high-cost laboratory equipment to affordable, robust devices capable of performing under field conditions. While centralized laboratories remain the gold standard, the time required for transport and processing often delays clinical decisions. POC technologies like Vis-NIR close this gap by enabling immediate, reagent-free analysis [15][16]. This shared potential aligns with the One Health perspective, fostering a comparative approach where insights from diverse physiological models contribute to a holistic diagnostic framework.

In human medicine, Vis-NIR has proven effective across various matrices, including hemoglobin quantification, glucose monitoring, and serum bilirubin prediction [21][22][23]. It has even been adapted to emerging challenges, such as assessing post-COVID conditions [24]. Similarly, in veterinary medicine, blood remains the most explored fluid for hemogram analysis in dogs, cats, and salmon [9][14][25], while fecal and milk samples have been used to screen for parasitic infections and dietary markers [26][27]. A summary of these diverse applications across both fields is presented in Table 1.

Table 1. Overview of Vis-NIR applications in human and veterinary medicine.

Field	Matrix	Main Applications	Key References
Human	Blood, Nasal fluids	Hemoglobin, glucose, bilirubin, Influenza A/B, post-COVID severity	[21][22][23][24][28][29]

Field	Matrix	Main Applications	Key References
Animal	Blood, Milk, Feces	Hemograms (dog/cat/salmon), milk feeding systems, parasitic screening	[1][13][25][26][27]

Despite these parallels, the wide variety of species in veterinary practice introduces unique challenges, such as species-specific differences in red blood cell shape and hemoglobin absorption. Furthermore, environmental variations like diet and stress add complexity to calibration models. However, when integrated with cloud-based AI, miniaturized Vis-NIR devices offer a non-invasive, affordable alternative that improves the standard of care for domestic and exotic species alike [13]. By facilitating both pre-diagnostic screening and post-diagnostic monitoring, this technology bridges the gap between human and animal healthcare, creating a collaborative space for diagnostic innovation.

7. Conclusions

Vis-NIR spectroscopy is a versatile tool that democratizes access to health technology by providing rapid, reagent-free results at the point of care. It complements centralized labs, allowing health professionals to act faster and with more confidence. Although challenges like environmental variation (diet, climate, stress) and spectral resolution persist, ongoing advancements in miniaturization and cloud-based machine learning promise to make these tools even more precise and accessible. Ultimately, this technology offers a bridge between fields, improving health outcomes for both people and animals alike.

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