BEHAVIOUR-BASED EARLY DETECTION OF PAIN AND DISEASE IN ANIMALS: ROLE OF PRECISION LIVESTOCK TECHNOLOGIES

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ABSTRACT

Early and accurate detection of pain and disease in livestock remains a pivotal challenge in veterinary medicine. Since animals cannot verbally communicate discomfort, behavioural changes including alterations in feeding, activity, posture, and social interaction—serve as the earliest detectable health indicators, often preceding overt clinical signs. Precision Livestock Technologies (PLT) are an emerging paradigm that integrates sensors, thermal imaging, computer vision, and AI to enable continuous, automated, and individualised behaviour monitoring. This review examines the biological basis of behaviour as a health indicator, the architecture and mechanisms of PLT, and their applications in detecting conditions such as lameness, mastitis, metabolic disorders, and reproductive events. We discuss the implications for animal welfare, production efficiency, and precision veterinary medicine. Challenges including data reliability, cost, and contextual adaptability are also addressed. Ongoing advancements in AI and sensor technology will further enhance the accessibility and predictive accuracy of PLT in diverse livestock settings.

Keywords: Precision livestock technology, animal behaviour, pain detection, disease monitoring, artificial intelligence, animal welfare, wearable sensors, computer vision.

1. Introduction

Early detection of pain and disease in animals remains a critical challenge in modern livestock production systems. Unlike humans, animals cannot verbally communicate discomfort, and clinical signs often appear only after significant disease progression has already occurred. This delay in detection frequently results in prolonged animal suffering, reduced productivity, and increased treatment costs, making proactive health surveillance a cornerstone of sustainable livestock management. Behavioural changes are among the earliest indicators of compromised health. Subtle deviations in activity, feeding patterns, posture, or social interactions often precede visible clinical signs by hours to days, providing a critical window for early intervention. Precision Livestock Technologies (PLT) have emerged as powerful tools to capture and analyse these behavioural changes in real time, enabling proactive disease management, improved animal welfare, and enhanced productivity across diverse production systems. Despite the acknowledged importance of monitoring behaviour, current on-farm practices still miss subtle early signs of discomfort or disease. Visual observation by farm personnel is subjective and inconsistent, and traditional diagnostic methods, such as laboratory tests, often confirm pathology only after significant progression has occurred. This critical delay limits the possibility of timely intervention. Precision Livestock Technologies (PLT) offer a solution by providing objective, continuous, and early detection capabilities that can close this gap. Therefore, behaviour-based precision monitoring is becoming essential for early intervention.

This review aims to consolidate current knowledge on the biological basis of behaviour-based disease detection, examine the technological architecture underpinning PLT, and critically evaluate documented applications and limitations. The implications for veterinary practice, animal welfare, and the evolving concept of precision veterinary medicine are also discussed.

2. Behaviour as an Indicator of Pain and Disease

Behaviour reflects the integrated physiological and pathological status of an animal. Pain and disease disrupt normal biological functions, leading to measurable alterations in observable behaviour. These alterations include reduced feed intake, decreased rumination, altered gait, abnormal postural adjustments, increased recumbency, and social withdrawal from conspecifics.

2.1 Biological basis of behavioural change

Pain or disease state activates complex neuroendocrine and inflammatory stress responses. These physiological shifts affect energy balance, leading to changes in appetite, posture, movement, and social behavior. Critically, these behavioural responses manifest before overt clinical signs are observable. Pain and disease alter physiology, and those physiological changes appear first as behaviour changes. For example, lameness in cattle is characterised by reduced locomotion, asymmetric gait, and uneven weight distribution, while mastitis may manifest as decreased feeding activity and marked changes in milking behaviour. Such behavioural changes arise as a consequence of inflammatory cascades, metabolic dysregulation, and neuroendocrine alterations triggered by the underlying pathological process. Critically, these behavioural indicators typically manifest before overt clinical symptoms become apparent, rendering them highly valuable for early detection and timely therapeutic intervention. The capacity to objectively quantify these subtle changes is, therefore, central to the clinical utility of PLT.

3. Concept and Architecture of Precision Livestock Technologies

Precision Livestock Technologies operate through an integrated three-tier system architecture comprising data acquisition, data processing, and decision support components.

The data acquisition layer involves the continuous collection of behavioural and physiological data using sensors and imaging systems deployed within the production environment. These data are transmitted through communication networks underpinned by the Internet of Things (IoT) to centralised storage infrastructure. The processing layer employs advanced computational techniques, including supervised machine learning and deep learning algorithms, to analyse behavioural patterns and detect statistically significant deviations from established baselines. Finally, the decision-support layer translates these analytical outputs into actionable, user-friendly insights for farm managers and attending veterinarians.

This architecture enables continuous, automated, and individualised monitoring of animals at scale, forming the operational foundation for reliable early disease detection in commercial livestock settings.

4. Mechanisms of Behaviour Monitoring Technologies

4.1 Wearable Sensors

Accelerometers and pedometers represent the most widely deployed PLT devices in commercial livestock settings. Attached to the neck, leg, or ear of the animal, these sensors measure acceleration along multiple axes and capture movement signatures. Proprietary and open-source algorithms subsequently convert raw acceleration data into meaningful behavioural metrics, including walking, standing, lying, and rumination. For instance, the repetitive jaw movements associated with rumination produce distinct and reproducible motion signatures that can be reliably detected and quantified.

4.2 Rumination and Feeding Sensors

Dedicated rumination monitoring systems utilise microphones or motion sensors strategically positioned to detect chewing activity. Acoustic and kinematic signals are processed through pattern recognition algorithms to estimate rumination duration and feeding time. A clinically meaningful decline in rumination time is well-established as an early indicator of metabolic and digestive disorders, including ketosis and subacute ruminal acidosis, providing a practical tool for herd health monitoring.

4.3 Thermal Imaging Systems

Infrared thermography captures surface temperature variations by detecting emitted thermal radiation from the animal's body. Regions of active inflammation, such as those associated with mastitis or podal lesions, characteristically exhibit elevated surface temperatures. Thermal imaging systems convert these signals into detailed temperature distribution maps, enabling the early identification of abnormal heat patterns indicative of underlying pathological processes.

4.4 Computer Vision Systems

Computer vision platforms capture continuous video or image data from animals within their production environment. Artificial intelligence models particularly convolutional neural network-based deep learning architectures analyse these visual data streams to automatically detect and quantify posture, gait characteristics, and body condition score. Changes in stride length, dorsal curvature, or asymmetric weight distribution can be identified as early indicators of lameness with an accuracy approaching or exceeding that of trained human observers.

4.5 Sensor Fusion and Intelligent Alerting

Contemporary PLT platforms increasingly integrate multiple data streams through sensor fusion methodologies. Machine learning models trained on extensive historical datasets establish individualised normal behavioural baselines for each animal. When real-time data deviate significantly from these personalised baselines, the system generates automated alerts for veterinary or managerial review. This multimodal approach demonstrably improves detection accuracy and reduces the rate of false-positive alerts compared to single-sensor systems.

5. Applications in Disease Detection

Precision Livestock Technologies have been evaluated and implemented across a range of clinically significant conditions in dairy and beef production systems. Lameness detection represents one of the most advanced and commercially validated PLT applications. Accelerometer-derived gait metrics and computer vision-based locomotion scoring have been shown to identify gait asymmetries and movement abnormalities with high sensitivity, enabling intervention at subclinical stages of the condition before welfare is severely compromised.

For metabolic disorders, continuous rumination monitoring has demonstrated utility in the early detection of ketosis and subacute ruminal acidosis in periparturient dairy cattle, conditions that carry significant implications for both animal welfare and farm profitability. Mastitis surveillance systems that integrate behavioural data, infrared thermographic findings, and automated milking system parameters have similarly shown promise for early quarter-level detection of intramammary infection. Reproductive monitoring platforms that continuously track activity levels have been widely adopted for oestrus detection and calving prediction, enabling timely and effective breeding interventions. Collectively, these applications illustrate the breadth of clinical utility achievable through behaviour-based PLT monitoring.

6. Implications for Animal Welfare

The relationship between early disease detection and animal welfare is direct and clinically significant. Timely therapeutic intervention reduces both the duration and severity of pain experienced by affected animals, improving recovery outcomes and minimising unnecessary suffering. Within the framework of the Five Freedoms and the evolving Five Domains Model, PLT contributes substantively to the freedom from pain, injury, and disease, as well as to the promotion of positive affective states. Continuous automated monitoring ensures that individual animals including those in large-scale intensive production systems where individual observation is logistically challenging are not overlooked. Furthermore, PLT facilitates evidence-based management, enabling targeted treatments and reducing dependence on population-level prophylactic interventions, thereby advancing both animal welfare and antimicrobial stewardship objectives.

7. Challenges and Limitations

Despite their considerable potential, Precision Livestock Technologies face several important operational and translational challenges. Data accuracy and reliability remain critical concerns, as sensor malfunction, displacement, or environmental interference can adversely affect measurement quality and generate erroneous alerts. Optimising the balance between diagnostic sensitivity and specificity is a persistent methodological challenge. Systems must achieve sufficient sensitivity to detect genuine health deviations while maintaining acceptable specificity to avoid alert fatigue among end-users. High initial capital costs and infrastructure requirements including reliable internet connectivity and compatible farm management software can present significant barriers to adoption, particularly in resource-limited production environments. Substantial variability in farm design, animal breeds, management practices, and climatic conditions complicates the generalisation of predictive models across settings. Algorithms developed and validated in one context may require recalibration before achieving equivalent performance in another. Finally, effective clinical utilisation requires that complex multivariate outputs be translated into simple, actionable recommendations that are accessible to farmers and field veterinarians without specialist data science training.

Key technical and practical barriers include: environmental noise, which compromises data accuracy and causes alert fatigue; breed-specific behavioural variations, which render uncalibrated models unreliable; prohibitive costs for small-scale operations, which restricts access to early detection; a lack of user trust in complex alerts, which delays critical interventions; and the necessity for local validation, without which unique environmental baselines degrade predictive performance.

8. Future Perspectives

Advancements in AI, miniaturized sensors, and cloud infrastructure are set to substantially enhance precision livestock monitoring systems. Future efforts will prioritize improving predictive accuracy, reducing costs, and expanding accessibility, particularly to smallholder contexts. By integrating multimodal data with real-time computing, PLT will enable more precise, individualized disease detection, thus augmenting veterinary expertise within the broader One Health framework of animal, human, and environmental sustainability. Importantly, PLT are envisioned as tools that complement and augment rather than replace the clinical expertise and judgement of veterinary professionals. Their greatest value lies in supporting timely, informed decision-making within a broader One Health framework that connects animal health, human health, and environmental sustainability.

9. Conclusion

Behaviour-based monitoring through Precision Livestock Technologies represents a significant and clinically meaningful advancement in the early detection of pain and disease in animals. Behavioural alterations serve as sensitive, objective indicators of compromised health, frequently manifesting before clinical signs become apparent to the observer. By integrating wearable sensors, thermal imaging, computer vision, and artificial intelligence within a cohesive decision-support architecture, PLT enables a proactive, individualised approach to animal health management. Behaviour-based monitoring is shifting veterinary practice from reactive treatment to early, preventive care. The future lies in integrating these data streams to create truly individualized, predictive, and "precision" veterinary medicine. While challenges related to cost, data quality, and contextual adaptability remain, the trajectory of technological development strongly supports the growing role of PLT in veterinary practice. The synthesis of behavioural science and technological innovation offers a compelling and practical pathway towards improved animal welfare, enhanced livestock productivity, and more sustainable food production systems objectives that lie at the heart of the veterinary profession's contribution to global One Health.

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