Popular Article

Behaviour Analytics in Precision Animal Farming: Transforming Welfare Assessment, Disease Prediction and Sustainable Livestock Management

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Abstract

Behaviour analytics integrated with Big Data is transforming precision animal farming by enabling continuous, objective, and predictive welfare assessment. Traditional welfare frameworks such as the Five Freedoms, Welfare Quality, and the Five Domains recognize welfare as multidimensional, but on-farm application has been limited by manual observation and subjective scoring. Precision Livestock Farming (PLF) overcomes these constraints through wearable sensors, environmental monitoring, IoT infrastructure, and AI-driven analytics that allow real-time, individual-level monitoring. Behavioural indicators including activity, rumination, feeding duration, posture changes, locomotion, and spatial distribution function as digital biomarkers, often revealing welfare compromise or disease onset before clinical signs appear. Integration of accelerometers, GPS systems, and physiological sensors with machine-learning models such as LSTM networks and Gradient Boosting Regression Trees enables early prediction of mastitis, ketosis, and lameness, supporting timely intervention and reduced antibiotic reliance. Beyond disease detection, behavioural analytics facilitates positive welfare assessment by identifying stable activity rhythms, social cohesion, and adaptive responses to environmental conditions. Despite its promise, challenges remain in data integration, interoperability, ethical governance, farmer adoption, and validation of automated welfare indices. As precision systems evolve toward integrated welfare-intelligence platforms combining behavioural, physiological, and environmental datasets, Big Data-driven livestock management is advancing toward production systems that are efficient, transparent, welfare-centred, and aligned with sustainability and One Health objectives.

Keywords: Animal Welfare, Behavioural Analytics, Big Data, Precision Livestock Farming, Predictive Disease Detection

Introduction

Animal welfare is increasingly recognized as a cornerstone of sustainable livestock production. Over the past several decades, scientific understanding of welfare has evolved from simple notions of health and productivity to complex multidimensional frameworks. Approaches such as the Five Freedoms, Welfare Quality, and Mellor's Five Domains model emphasize that welfare encompasses nutrition, environment, health, behaviour, and the resulting mental state. These frameworks highlight that welfare is not merely the absence of disease but includes the animal's ability to express normal behaviour and experience positive states. Despite this conceptual clarity, practical on-farm welfare assessment remains challenging. Conventional assessment methods rely on visual inspection, manual scoring, and periodic audits conducted by trained observers. Such approaches are time-consuming, subjective, and often limited in frequency. In modern production systems where herd sizes are large and labour availability is limited, detecting subtle behavioural changes through human observation alone becomes increasingly difficult.

Precision Livestock Farming (PLF) has emerged as a transformative approach to address these limitations. PLF applies sensor technologies, automated data acquisition, and advanced analytics to monitor animals continuously and individually rather than at group level. The integration of Internet of Things (IoT) infrastructures and Artificial Intelligence (AI) models further enhances the ability to interpret complex behavioural and physiological patterns in real time. At the heart of this transformation lies behavioural analytics. Animals constantly communicate their internal states through movement, feeding patterns, rumination, posture changes, social interactions, and vocalizations. Deviations in these behavioural patterns often precede visible clinical symptoms. When captured as digital signals and processed using Big Data analytics, behaviour becomes a predictive biomarker rather than a retrospective observation.

Welfare Frameworks and the Need for Continuous Monitoring

Animal welfare science acknowledges that welfare is multidimensional. The Five Freedoms framework focuses on freedom from hunger, discomfort, pain, and fear, along with freedom to express normal behaviour. The Welfare Quality framework structures welfare into principles such as good feeding, good housing, good health, and appropriate behaviour, each subdivided into measurable criteria. Mellor's Five Domains model further refines this approach by linking physical domains to the animal's mental state. Although comprehensive, these frameworks require extensive data collection and professional assessment. Welfare audits are often infrequent due to time and cost constraints. Furthermore, attempts to use single

"iceberg indicators" to represent overall welfare have proven insufficient. Welfare cannot be reliably inferred from a single metric.

Precision technologies offer a potential solution by enabling continuous, automated monitoring of multiple welfare-related parameters. Behaviour, feeding patterns, health indicators, and environmental conditions can all be recorded simultaneously. The possibility of integrating these data streams into automated welfare assessment systems has been suggested, although further validation is required.

Big Data in Precision Livestock Farming

Big Data in livestock systems is characterized by high volume, velocity, variety, and complexity. Modern farms equipped with wearable sensors generate thousands of data points per animal per day. IoT-based infrastructures combine animal-mounted devices with wireless transmission systems and cloud-based analytics platforms. These sensors record body temperature, activity and acceleration, rumination frequency, feeding duration, posture transitions, heart rate variability, environmental parameters such as humidity and ambient temperature.

In IoT-AI architectures, sensor nodes transmit data via low-power networks to centralized servers where pre-processing and modelling occur. Pre-processing techniques include smoothing filters, interpolation of missing values, synchronization of time-series data, and outlier removal. These steps ensure data reliability before machine learning analysis. Such continuous monitoring shifts farm management from episodic inspection to dynamic surveillance. Instead of waiting for overt symptoms, deviations from established behavioural baselines trigger alerts for early intervention.

Behaviour as a Digital Biomarker

Behaviour is often the earliest indicator of welfare compromise. Animals follow structured daily activity budgets involving grazing, resting, ruminating, walking, and social interaction. Variations in these patterns provide valuable information about internal physiological states and environmental conditions. Accelerometers are widely used to measure acceleration in one, two, or three axes, enabling classification of behaviours such as lying, standing, walking, grazing, and ruminating. Studies in cattle and small ruminants frequently report accuracy levels exceeding 85–95% in behaviour classification. For example, accelerometer-based systems have successfully monitored rumination, feeding, oestrus, lameness, and parturition events.

Global Positioning System (GPS) sensors complement accelerometers by providing spatial context. GPS tracking reveals grazing patterns, travel distances, water-seeking

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behaviour, and social clustering. In extensive systems, GPS data help identify pasture utilization and resource dependency. Combining accelerometers with GPS enhances classification accuracy because motion patterns can be interpreted within spatial context. Thus, behavioural data become digital biomarkers reflecting welfare and health status.

IoT-AI Architectures and Predictive Modelling

The integration of IoT and AI represents a major advancement in precision livestock farming. Hybrid modelling approaches combining Long Short-Term Memory (LSTM) networks and Gradient Boosting Regression Trees (GBRT) have demonstrated strong predictive performance. LSTM networks are particularly suited for time-series data because they capture temporal dependencies in behavioural sequences. GBRT models contribute interpretability by ranking feature importance and identifying which variables most strongly predict disease.

In a field-based dairy trial, such hybrid systems achieved high predictive accuracy in detecting mastitis, ketosis, and lameness up to 48 hours before veterinary confirmation. Behavioural changes such as reduced feeding duration, altered lying patterns, and decreased activity served as early warning signals. Traditional threshold-based systems rely on fixed cut-offs and often generate false positives. In contrast, AI-driven systems establish individualized baselines for each animal, increasing sensitivity and specificity. This personalization enhances both welfare and economic efficiency.

Applications Across Species and Production Systems

Precision behavioural analytics has been applied extensively in cattle, sheep, and goats. In dairy cattle, accelerometers detect oestrus, lameness, illness onset, and calving. Lameness detection is particularly important because early intervention prevents chronic pain and productivity loss. In sheep systems, accelerometers and GPS sensors monitor grazing behaviour, lambing events, and social distribution. In goats, seasonal variations in grazing and movement patterns have been characterized using combined sensor systems. Environmental monitoring also contributes to welfare assessment. Climate control systems regulate temperature and humidity in housing units. Indirect indicators such as spatial distribution or vocalization patterns may signal heat stress or discomfort. These applications demonstrate the versatility of behavioural analytics across both intensive and extensive systems.

Welfare Enhancement and One Health Implications

Early disease detection reduces animal suffering and limits the severity of illness. By identifying subclinical conditions before visible symptoms emerge, precision systems enable timely treatment and reduce reliance on antibiotics. This contributes to antimicrobial

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stewardship and aligns with One Health principles. Behavioural analytics also supports positive welfare by identifying patterns associated with comfort, social stability, and environmental enrichment. Stable activity rhythms and balanced social interactions may indicate a favourable welfare state. Furthermore, digital welfare monitoring enhances transparency and traceability. Consumer demand for ethically produced animal products is increasing. Automated welfare indices derived from sensor data may support certification and quality assurance programs.

Challenges and Limitations

Despite its promise, precision livestock farming faces practical and ethical challenges. Many systems operate independently and lack full multidimensional integration. Interoperability between devices from different manufacturers remains limited. Data management requires technical expertise. Farmers may initially resist adoption due to perceived complexity or reduced human-animal interaction. Education and user-friendly interfaces are critical for successful implementation. Ethically, technology must enhance not replace attentive husbandry. There is a risk that automation could be used solely to intensify production without improving welfare. Responsible governance and continuous validation are essential.

Future Directions: Toward Integrated Welfare Intelligence Systems

The future of precision animal farming lies in integrated welfare intelligence systems that combine behavioural, physiological, and environmental data into unified dashboards. Such systems could generate real-time welfare indices aligned with established frameworks. Advances in explainable AI may improve transparency in decision-making processes. Edge computing could reduce latency, enabling faster on-farm alerts. Integration with genomic and production data may further enhance predictive capability. Research should focus on validating automated welfare assessment models against established scoring protocols and exploring how behavioural analytics can measure positive affective states.

Conclusion

Big Data and behavioural analytics are shifting precision animal farming from reactive to predictive, welfare-focused management. Continuous behavioural monitoring combined with AI enables early disease detection, environmental optimization, and improved welfare assessment. These technologies provide measurable indicators across nutrition, health, environment, and behaviour domains, aligning with multidimensional welfare frameworks. IoT-AI systems show strong predictive accuracy, and wearable and positioning tools effectively monitor ruminant behaviour. Despite challenges in integration and ethics, the

fusion of behavioural science and digital analytics supports more productive, sustainable, and welfare-centred livestock systems.

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