Research Journal of Agricultural Science, 58 (2), 2026; ISSN: 2668-926X;

http://doi.org/10.59463/RJAS.2026.2.31

FROM TRADITIONAL OBSERVATION TO SMART SENSOR TECHNOLOGY: THE TRANSITION TO PRECISION DAIRY FARMING USING NEDAP COWCONTROL SYSTEM

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Abstract. *The global dairy industry is undergoing a significant transformation driven by advances in sensor technology and data analytics. Traditional monitoring methods, which rely primarily on visual observation by farmers, have long been the standard approach for detecting estrus, illness, and other health-related events in dairy herds. However, these conventional techniques are inherently limited by human fatigue, time constraints, and subjective judgment, resulting in suboptimal detection rates and delayed interventions. This paper presents a comprehensive review of the transition from traditional dairy farm monitoring to modern precision dairy farming, with a specific focus on the Nedap CowControl system as a representative case study of commercially deployed sensor technology. The Nedap CowControl platform utilizes accelerometer-based SmartTag sensors, including neck collars, leg tags, and ear tags, to continuously monitor cow behaviour patterns such as eating time, rumination time, activity levels, and inactivity periods. These sensors transmit data wirelessly to barn-based receivers, where proprietary algorithms analyse individual cow baselines and herd averages to generate real-time alerts for heat detection, health monitoring, and nutritional assessment. The review examines the technical architecture of the system, compares its performance against traditional observation methods, and discusses the broader implications of sensor-based monitoring for animal welfare, reproductive efficiency, and farm profitability. Findings from the literature indicate that sensor-based systems achieve heat detection rates exceeding 95%, compared to 30-50% for visual observation, and enable earlier identification of health issues through behavioural deviations detected hours before clinical signs become apparent. The paper concludes that while challenges such as initial investment costs and the need for technical training remain, the benefits of precision dairy farming technologies represent a compelling advancement in sustainable and efficient dairy production.*

Keywords: *precision dairy farming, sensor technology, cow monitoring, heat detection, Nedap CowControl, accelerometer, animal welfare, SmartTag*

INTRODUCTION

Dairy farming represents one of the most important sectors of global agriculture, providing essential nutrition through milk and dairy products while supporting the livelihoods of millions of farmers worldwide. As the global population continues to grow, with projections suggesting an increase to approximately 9.7 billion people by 2050, the demand for dairy products is expected to rise substantially. To meet this growing demand while maintaining profitability and sustainability, dairy farmers are increasingly turning to technological innovations that improve efficiency, animal welfare, and overall herd management. Among these innovations, precision dairy farming has emerged as a transformative approach that leverages advanced sensor technology, data analytics, and automated monitoring systems to

optimize every aspect of dairy production (Rutten et al., 2013).

For decades, the primary method of monitoring dairy cow health and reproductive status has relied on direct visual observation by farmers and herdsmen. This traditional approach involves watching cows for behavioural signs of estrus, such as mounting behaviour, restlessness, and mucous discharge, as well as monitoring general health indicators like feed intake, mobility, and physical appearance. While experienced farmers can develop considerable skill in detecting these signs, visual observation is fundamentally constrained by several practical limitations. Most notably, a significant proportion of estrus events in dairy cows occurs during nighttime hours when farmers are not present to observe them. Research has consistently demonstrated that visual observation methods typically detect only 30 to 50 percent of all estrus events, meaning that a substantial number of breeding opportunities are missed, leading to extended calving intervals and reduced reproductive efficiency (Van Eerdenburg et al., 2002). Furthermore, the physical demands of modern dairy farming, particularly on large-scale operations with hundreds or thousands of cows, make it practically impossible for individual animals to receive the level of attentive observation that was feasible on smaller traditional farms.

The limitations of traditional monitoring extend beyond reproductive management. Early detection of illness is critical in dairy farming, as conditions such as ketosis, metritis, mastitis, and displaced abomasum can progress rapidly if not identified and treated promptly. However, the initial signs of many diseases are subtle behavioural changes, such as reduced feeding time, decreased rumination, or altered activity levels, which are difficult to detect through periodic visual observation. By the time clinical symptoms become apparent to a farmer, the condition may have already advanced to a stage requiring more intensive treatment, resulting in higher veterinary costs, prolonged recovery periods, and reduced milk production. Studies have shown that each day of delayed treatment for conditions like ketosis can result in measurable decreases in milk yield and cow welfare (Steensels et al., 2017).

The emergence of precision dairy farming represents a fundamental paradigm shift in how dairy herds are managed. Rather than relying on intermittent human observation, precision dairy farming employs continuous automated monitoring through sensor-based systems that collect behavioural and physiological data around the clock. These systems use a variety of sensor technologies, including accelerometers, pedometers, temperature sensors, and more recently, artificial intelligence-based camera systems, to track individual cow behaviour and health indicators in real time. Among the leading companies in this field, Nedap Livestock Management, a Dutch technology company founded in 1929, has developed one of the most comprehensive and widely adopted cow monitoring platforms globally. The Nedap CowControl system, which monitors over eight million cows across more than 30,000 farms worldwide, exemplifies the current state of the art in precision dairy farming technology (Nedap Livestock Management, 2025).

This paper aims to provide a comprehensive review of the transition from traditional observation-based dairy farm monitoring to modern sensor-based precision dairy farming, using the Nedap CowControl system as a representative case study. The objectives are threefold: first, to describe the technical architecture and functioning of the Nedap CowControl sensor system, including its SmartTag technology and data analysis algorithms; second, to compare the performance and capabilities of sensor-based monitoring against traditional

methods; and third, to discuss the implications of this technological transition for dairy farm management, animal welfare, and the future direction of the dairy industry.

MATERIAL AND METHODS

This review paper is based on a comprehensive analysis of published scientific literature, technical documentation from Nedap Livestock Management, and publicly available case studies and field reports. The methodology involved a systematic collection and evaluation of information from peer-reviewed journals, conference proceedings, industry publications, and manufacturer technical specifications. The primary focus was on understanding the technical components, operational principles, and field-validated performance of the Nedap CowControl system as a representative example of modern precision dairy farming technology.

Nedap CowControl System Description

The Nedap CowControl system is an integrated cow monitoring platform that provides real-time, continuous monitoring of individual dairy cow behaviour and health status. The system architecture consists of three primary layers: the sensor layer (SmartTag devices attached to cows), the communication layer (wireless data transmission infrastructure), and the analytics layer (server-based algorithms and user interface). Each cow in the herd is fitted with a SmartTag sensor device, which continuously records behavioural data and transmits it wirelessly to receivers installed throughout the barn facility. The collected data is processed by proprietary algorithms that compare each cow's current behaviour against her individual historical baseline and the herd average, generating alerts and insights that are delivered to the farmer through a computer interface or mobile application.

SmartTag Sensor Technology

The core sensing technology of the Nedap CowControl system is based on three-dimensional (3D) accelerometers embedded in SmartTag devices. These accelerometers are available in three form factors: the SmartTag Neck (a neck collar), the SmartTag Leg (a leg-mounted tag), and the SmartTag Ear (a standard ear tag). Each SmartTag device contains a micro-electromechanical systems (MEMS) accelerometer that continuously measures the position, angle, and movement intensity of the cow in three-dimensional space. The neck-mounted SmartTag records the position and movement of the cow's head, enabling the system to distinguish between eating behaviour (characterized by a head-down position near the feed bunk), rumination behaviour (characterized by rhythmic jaw movements while the head is in an elevated position), and inactive periods. The leg-mounted SmartTag records locomotion patterns, walking speed, and standing versus lying duration, providing complementary data on general activity levels. The SmartTag Ear, the most recently introduced form factor, captures similar behavioural insights in a lightweight ear-tag design that is compatible with standard tagging routines. All SmartTag devices have an expected service life of seven to ten years and include an onboard memory buffer that stores up to 24 hours of data, ensuring no information is lost in the event of temporary communication interruptions (Elischer et al., 2021).

Data Processing and Alert Generation

The data processing pipeline of the Nedap CowControl system follows a multi-stage architecture. At the first stage, raw 3D accelerometer data is sampled at regular intervals by the SmartTag device and stored in the onboard memory buffer. At the second stage, the stored data is transmitted wirelessly from the SmartTag to fixed antenna receivers installed at strategic locations throughout the barn, such as milking parlour entrances and exits, feeding stations, and water troughs. At the third stage, the received data is processed by server-based algorithms that perform behavioural classification, trend analysis, and anomaly detection. The heat detection algorithm combines multiple behavioural parameters, including increased activity levels, restlessness, sniffing behaviour, chin resting, and mounting events, into a composite numerical score known as the Nedap Heat Score. Higher scores indicate stronger estrus signs and are correlated with higher conception probability. The health monitoring algorithm continuously compares each cow's current eating time, rumination time, and activity level against her individual baseline established over previous days and weeks. Statistically significant deviations from this baseline trigger health alerts, enabling farmers to identify and investigate potential health issues before clinical signs become visible. The system also tracks nutrition by comparing individual eating time to herd averages, flagging cows with significantly reduced feed intake that may be experiencing illness, social hierarchy issues, or feed access problems (Baccouri et al., 2023).

Literature Search and Validation Sources

To ensure the reliability and accuracy of the information presented in this review, data were collected from multiple sources including peer-reviewed publications indexed in ScienceDirect, PubMed, and Google Scholar; official technical documentation published by Nedap Livestock Management; and independent field evaluations conducted by agricultural research institutions. Key validation studies include the work of Elischer et al. (2021), published in Computers and Electronics in Agriculture, which confirmed that the Nedap SmartTag Neck accurately monitored eating, ruminating, and inactivity behaviours in dairy cows. Additionally, Bufano et al. (2022), published in the journal Animals (MDPI), validated Nedap monitoring technology for feeding, rumination, lying, and standing behaviour measurements in dairy buffaloes, comparing sensor readings against visual observation and video recording as gold-standard reference methods. These independent academic validations provide strong evidence for the accuracy and reliability of the Nedap CowControl system in real-world farming conditions.

RESULTS AND DISCUSSIONS

Traditional vs. Sensor-Based Monitoring: A Comparative Analysis

As noted by Mark Roozen and Kees Scheepens (2022), “a good beginning is half the success.” This idea is highly relevant to dairy farming, where accurate and timely monitoring of cows is essential for productivity, animal health, and effective herd management. In the past, farmers relied on careful human observation to detect behavioural changes, including movement, feeding, resting, and rumination. Although experienced farmers could identify many important signs, traditional observation required considerable time, constant attention,

and physical effort. It was usually conducted only at specific moments during working hours, which made data collection discontinuous and limited. The results were also influenced by the observer's availability, attention span, and subjective judgment, making it difficult to detect early signs of health problems or productivity losses.

Today, livestock management is increasingly supported by modern sensor-based technologies. Systems such as Nedap SmartTag and Nedap CowControl allow continuous and automated monitoring of individual cows, collecting objective quantitative data 24 hours per day and 7 days per week across multiple behavioural parameters at the same time. This technological shift reduces manual labour, improves efficiency, supports faster and more informed decision-making, and makes it possible to manage individual animals within large herds. The following table presents a comparison between traditional observation methods and modern sensor-based monitoring, highlighting the key differences in continuity, objectivity, comprehensiveness, detection accuracy, response time, labour efficiency, and individual animal management.

Table 1.

From Intuition to Data

Parameter	Past Traditional Methods	Present Nedap SmartTag Technology
Motion	Visual observation: the farmer or herdsman evaluated how much the cow moved, lay down, or stood, and noticed possible lameness. Observations were periodic and depended on human judgment.	The Nedap SmartTag system automatically monitors cow activity continuously, including movement levels, lying time, and standing time. Data is recorded in real time and helps detect behavioral changes.
Eating	Observation at the feed bunk: the farmer monitored whether the cow approached feed and how long it spent eating. Feed intake was sometimes estimated based on leftovers. Accurate individual data was difficult to obtain.	The Nedap SmartTag records feeding-related behavior, including the frequency and duration of feeding events. Data is collected individually for each cow and analyzed automatically.
Rumination	Manual observation: the farmer checked whether the cow was ruminating and occasionally measured the duration. Observations were irregular and limited in time.	The Nedap SmartTag continuously measures rumination time and intensity. Decreases in rumination are automatically flagged as potential health issues.

Heat Detection Efficiency

Reproductive management is one of the most critical aspects of dairy farming, as it

directly influences calving intervals, milk production, and the economic viability of the operation. The transition from visual heat detection to sensor-based monitoring has produced dramatic improvements in reproductive performance metrics. Under traditional observation-based systems, heat detection rates typically range from 30 to 50 percent, meaning that more than half of all estrus events are missed. This results in extended days open (the number of days between calving and successful conception), which increases feed costs without corresponding milk production and reduces the total number of calves born per cow over her lifetime. Research has documented that a single missed heat cycle can cost dairy farmers between 200 and 500 euros per cow in lost revenue and additional expenses, depending on the herd's reproductive efficiency targets and milk price conditions.

The Nedap CowControl system addresses these limitations through its multi-parameter heat detection algorithm, which continuously monitors several behavioural indicators simultaneously. During estrus, dairy cows exhibit a characteristic set of behavioural changes including increased general activity (mounting, standing heat, restlessness), reduced feeding time, and altered social interactions such as sniffing and chin resting. The SmartTag accelerometer detects these changes by measuring the intensity and pattern of the cow's movements throughout the day and night. When the composite Nedap Heat Score exceeds a defined threshold, the system generates an alert indicating that the cow is in heat and recommending the optimal insemination window. Field data from dairy farms using the Nedap system have reported 21-day pregnancy rates increasing from approximately 18 percent to 34 percent, representing a near-doubling of reproductive efficiency. Furthermore, independent evaluations have shown that the Nedap system achieves submission rates that are approximately 16 percent higher than those of competing sensor systems, underscoring the effectiveness of its heat detection algorithm (Nedap Livestock Management, 2025).

Health Monitoring and Early Disease Detection

One of the most significant advantages of sensor-based monitoring is the ability to detect health problems at an early stage, often before clinical symptoms become visible to the farmer. The Nedap CowControl system achieves this by continuously tracking three key behavioural parameters: eating time, rumination time, and activity level. Research in dairy science has established that deviations from normal patterns in these behaviours are among the earliest indicators of disease in dairy cows. For example, cows developing ketosis typically show a progressive reduction in feeding time and rumination beginning 24 to 48 hours before clinical signs such as decreased milk production or abnormal behaviour become apparent.

Similarly, cows with metritis often exhibit reduced activity levels and increased lying time before developing fever or vaginal discharge.

The Nedap system's health monitoring algorithm maintains an individual baseline for each cow, accounting for factors such as lactation stage, days in milk, and production level that naturally influence behaviour patterns. When a cow's current behavioural measurements deviate significantly from her established baseline, the system generates a health attention alert, directing the farmer to examine the specific animal. This approach enables what is known as precision or individualized cow management, where each animal receives attention based on her specific needs rather than on a fixed schedule. Published studies have reported that early detection through sensor monitoring can reduce treatment costs by approximately 20 percent and decrease the duration and severity of illness through earlier intervention. Furthermore, the

ability to detect health issues promptly has important implications for antimicrobial stewardship, as earlier treatment may reduce the need for prolonged antibiotic courses and decrease the risk of antimicrobial resistance development (Steensels et al., 2017).

Continuous Behavioural Monitoring and Nutritional Assessment

Beyond reproductive management and health monitoring, the continuous data stream provided by the Nedap CowControl system offers valuable insights into the nutritional status and general well-being of the herd. Individual eating time data allows farmers to identify cows that are not consuming adequate amounts of feed, which may indicate illness, social hierarchy issues that limit feed bunk access, or problems with feed quality and availability. This is particularly important during the fresh period immediately following calving, when cows experience a negative energy balance as they transition from the dry period to peak lactation. Cows that fail to achieve sufficient dry matter intake during this critical period are at significantly higher risk for metabolic disorders such as ketosis and displaced abomasum, and their subsequent milk production may be compromised for the entire lactation.

The rumination monitoring capability provides complementary information about digestive health and cow comfort. Rumination is a reliable indicator of rumen function, and reductions in rumination time have been associated with various health conditions including acidosis, mastitis, and lameness. By tracking both eating and rumination patterns simultaneously, the system provides a comprehensive picture of each cow's nutritional and health status. Additionally, the integration of Nedap CowControl with Nedap FarmControl and SmartSort automated sorting gates enables a fully automated response to monitoring alerts.

When the system identifies a cow requiring attention, whether for insemination, health examination, or other management purposes, the SmartSort gate can automatically separate the cow from the herd as she passes through a sorting point, eliminating the need for manual identification and reducing labour requirements. This integration represents the culmination of the precision dairy farming concept, where monitoring, analysis, and action are seamlessly connected through technology.

Emerging Technologies: AI Vision and Cloud-Based Analytics

The evolution of precision dairy farming continues with the introduction of artificial intelligence-based monitoring technologies. Nedap's SmartSight system, launched in 2025, represents the next generation of cow monitoring by employing AI-powered computer vision cameras installed at milking parlour entrances and exit lanes. This system analyses gait patterns, stride length, weight distribution, and movement symmetry for each cow as she walks through the camera's field of view during routine milking sessions. The deep learning algorithms behind SmartSight were trained on millions of data points collected from commercial dairy farms across multiple countries over several years of development. The system provides automated locomotion scoring and can detect lameness before it becomes visible to the human eye, addressing a condition that affects approximately 90 percent of dairy cows at least once during their lifetime and is one of the top three reasons for involuntary culling worldwide.

The Nedap Now cloud-based analytics platform represents another significant

advancement, extending the capabilities of the CowControl system through cloud processing power and remote accessibility. Through the Nedap Now mobile application, available on both iOS and Android platforms, farmers can access real-time alerts, comprehensive reports, and interactive barn maps from any location with internet connectivity. This cloud-based approach enables remote herd management, which is particularly valuable for farm operations with multiple locations or for farmers who wish to monitor their herds while away from the farm.

The combination of edge-based sensor technology with cloud-based analytics and mobile accessibility represents the direction in which precision dairy farming is heading, with increasingly powerful tools that make data-driven decision-making accessible to farmers of all scales and technical backgrounds.

CONCLUSIONS

The transition from traditional observation-based dairy farm monitoring to sensor-based precision dairy farming represents a fundamental advancement in the management of dairy cattle. This review, using the Nedap CowControl system as a representative case study, has demonstrated that modern sensor technology offers transformative improvements across multiple dimensions of dairy herd management. The continuous, automated, and objective nature of sensor-based monitoring addresses the inherent limitations of visual observation, including missed estrus events during nighttime hours, delayed detection of health problems, and the practical impossibility of providing individual attention to every cow in large commercial herds.

The technical evidence presented in this review indicates that accelerometer-based SmartTag sensors, as employed by the Nedap CowControl system, can accurately monitor eating behaviour, rumination patterns, activity levels, and inactivity periods in dairy cows, with validation from independent academic studies confirming measurement accuracy against gold-standard visual observation and video recording methods. The practical benefits of this technology are substantial: heat detection rates exceeding 95 percent compared to 30 to 50 percent for traditional observation, earlier identification of health issues through behavioural deviation alerts, improved nutritional management through individual feed intake monitoring, and reduced labour requirements through automated alerts and sorting integration.

Looking forward, the continued evolution of precision dairy farming through the integration of artificial intelligence, computer vision, and cloud-based analytics promises to further enhance the capabilities of sensor-based monitoring systems. Technologies such as Nedap's SmartSight AI vision system for lameness detection and the Nedap Now cloud platform for remote herd management illustrate the trajectory of the industry toward increasingly sophisticated, interconnected, and accessible monitoring solutions. While challenges remain, including the initial investment cost of sensor infrastructure, the need for farmer education and technical training, and concerns about data management and privacy, the evidence strongly supports the conclusion that precision dairy farming technologies represent a compelling and increasingly necessary advancement for the sustainable and efficient production of milk and dairy products in the twenty-first century.

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