

Evaluating the Effectiveness of Smart Sensors in Livestock Health Monitoring

Haimei Wang ✉

Hainan Institute of Biotechnology, Haikou, 570206, Hainan, China

✉ Corresponding author: haimei.wang@hibio.org

International Journal of Molecular Zoology, 2024, Vol.14, No.6 doi: [10.5376/ijmz.2024.14.0029](https://doi.org/10.5376/ijmz.2024.14.0029)

Received: 10 Nov., 2024

Accepted: 12 Dec., 2024

Published: 22 Dec., 2024

Copyright © 2024 Wang. This is an open access article published under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Preferred citation for this article:

Wang H.M., 2024, Evaluating the effectiveness of smart sensors in livestock health monitoring, International Journal of Molecular Zoology, 14(6): 326-333 (doi: [10.5376/ijmz.2024.14.0029](https://doi.org/10.5376/ijmz.2024.14.0029))

Abstract This study explores various types of intelligent sensors used for livestock management, including biometric sensors for physiological monitoring, environmental sensors for farm level assessment, and integrated systems that combine multiple functions. The applied technologies cover disease prevention, improving animal welfare, and advancing precision livestock practices. The main advantages of using intelligent sensors include improved real-time monitoring, cost savings in livestock management, and their contribution to sustainable agriculture. A case study on the implementation of intelligent sensors in dairy farms highlights practical achievements and challenges, providing a broader impact for the industry. Looking ahead, the integration of emerging technologies such as the Internet of Things, artificial intelligence, and biosensing, coupled with collaborative frameworks and policy support, is expected to overcome current obstacles. This study aims to emphasize the transformative potential of intelligent sensors in enhancing livestock health monitoring, paving the way for more sustainable and efficient agricultural practices.

Keywords Livestock health monitoring; Smart sensors; Precision livestock farming; Sustainable agriculture; IoT in farming

1 Introduction

Smart sensors have revolutionized livestock health monitoring by providing real-time data and insights into animal health and behavior. These sensors, often integrated with the internet of things (IoT), enable continuous monitoring of various health parameters such as temperature, heart rate, and location, which are crucial for early disease detection and management (Rahmawati et al., 2023; Schulthess et al., 2023). Wearable devices and biosensors are particularly effective in tracking eating habits, rumination, and physical activity, thereby allowing farmers to make informed decisions to enhance productivity and animal welfare (Go et al., 2022). The deployment of wireless sensor networks (WSNs) and IoT platforms has further facilitated the automation of livestock monitoring, reducing the need for manual labor and improving the efficiency of farm operations (Rajendran et al., 2023).

Livestock health is a critical component of global food security and economic stability (Stygar et al., 2021). Healthy livestock contribute significantly to the production of meat, dairy, and other animal products, which are essential for meeting the nutritional needs of a growing global population. The livestock industry also plays a vital role in the economies of many countries, particularly in developing regions where it is a major source of income and employment (Arshad et al., 2022). Ensuring the health and welfare of livestock through advanced monitoring technologies can lead to increased productivity, reduced disease outbreaks, and lower production costs, thereby supporting sustainable agricultural practices and economic growth (Džermeikaitė et al., 2023; Sahoo et al., 2024).

This study evaluates the effectiveness of intelligent sensors in enhancing livestock health monitoring, including examining the current status of sensor technology, their applications in disease detection and management, and their impact on farm productivity and animal welfare. It explores the challenges and limitations associated with implementing these technologies, such as the need to validate and integrate sensor data into farm management systems. This study aims to emphasize the potential of intelligent sensors in changing animal husbandry, promoting global food security, and economic stability through a comprehensive analysis of existing literature and technologies.

2 Types of Smart Sensors in Livestock Monitoring

2.1 Biometric sensors for physiological data collection

Biometric sensors are crucial for monitoring the physiological health of livestock. These sensors are often integrated into wearable devices such as smart collars, which can measure heart rate and body temperature. For instance, the use of pulse sensors and temperature sensors like the MLX90614 in smart collars allows for precise monitoring of these vital signs, providing real-time data to farmers and veterinarians (Figure 1) (Arshad et al., 2022). This continuous monitoring helps in early detection of health issues, thereby improving animal welfare and productivity. Motion and activity tracking sensors are essential for assessing the physical activity and behavior of livestock. These sensors can detect changes in movement patterns, which may indicate health problems or stress. Wearable devices equipped with accelerometers and GPS modules are commonly used to track the location and activity levels of animals, providing valuable insights into their daily routines and overall well-being (Džermeikaitė et al., 2023). Detecting stress and fatigue in livestock is vital for maintaining their health and productivity. Sensors that monitor physiological parameters such as heart rate variability and activity levels can help identify signs of stress and fatigue. By analyzing these data, farmers can implement timely interventions to alleviate stress and improve animal welfare (Yazdanbakhsh et al., 2017).

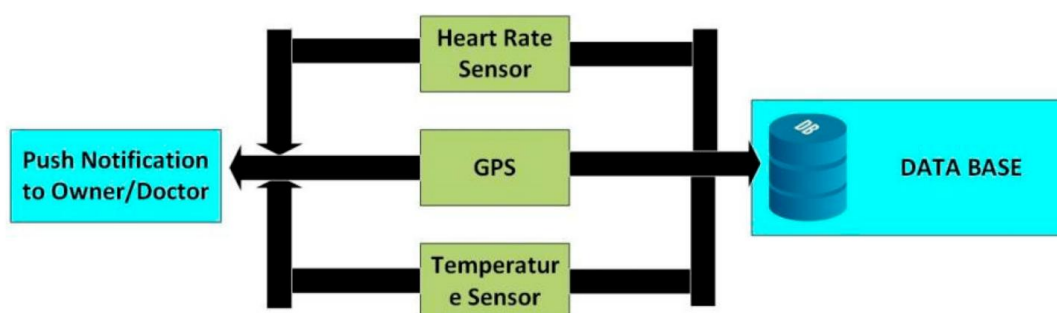


Figure 1 Total parameters for the cow collar (Adopted from Arshad et al., 2022)

2.2 Environmental sensors for farm-level monitoring

Environmental sensors play a significant role in monitoring farm conditions. Climate and temperature sensors help maintain optimal environmental conditions for livestock by tracking temperature fluctuations and ensuring a stable climate within the farm. These sensors are often part of an integrated system that regulates environmental parameters to enhance animal health and productivity (Rajendran et al., 2023). Humidity and air quality sensors are crucial for ensuring a healthy environment for livestock. These sensors monitor the levels of humidity and pollutants in the air, which can affect animal health. By maintaining optimal air quality, farmers can prevent respiratory issues and other health problems in their livestock (Iwasaki et al., 2019). Water quality is essential for livestock health, and sensors that monitor water parameters such as pH, temperature, and contamination levels are vital. These systems ensure that livestock have access to clean and safe drinking water, which is crucial for their overall health and productivity.

2.3 Integrated systems combining multiple sensor types

Wearable smart collars and ear tags are examples of integrated systems that combine multiple sensor types to provide comprehensive health monitoring. These devices can track physiological data, location, and environmental conditions, offering a holistic view of an animal's health and well-being (Rahmawati et al., 2023). Automated monitoring stations are fixed installations that use a combination of sensors to monitor environmental and physiological parameters. These stations can provide continuous data collection and analysis, enabling real-time decision-making and management of livestock health. Real-time data analytics platforms are essential for processing and analyzing the vast amounts of data generated by smart sensors. These platforms use advanced algorithms to interpret sensor data, providing actionable insights that help farmers make informed decisions about livestock management and health interventions (Halachmi et al., 2019; Ronald and Raman, 2024).

3 Applications of Smart Sensors in Livestock Health

3.1 Disease prevention and early diagnosis

Smart sensors play a crucial role in identifying infectious disease outbreaks in livestock by providing continuous health monitoring and early warning systems. For instance, animal-mounted sensors can automatically and continuously monitor health indicators, allowing for the early detection of diseases before they spread widely within a herd (Yazdanbakhsh et al., 2017). These systems can forecast illnesses up to seven days in advance, significantly reducing morbidity and mortality rates. Wearable sensors and IoT-based systems enable the monitoring of individual animal health trends by tracking vital signs such as temperature, heart rate, and activity levels in real-time (Arshad et al., 2022). This continuous data collection allows for the detection of deviations from normal health patterns, facilitating timely interventions. Smart sensors can also track the effectiveness of vaccinations and treatments by monitoring physiological responses and health improvements over time. This data-driven approach helps in assessing the success of medical interventions and adjusting treatment plans as necessary (Džermeikaitė et al., 2023).

3.2 Improving animal welfare and productivity

Smart sensors contribute to reducing stress in livestock by managing environmental conditions such as temperature and humidity. Intelligent systems can regulate these parameters automatically, ensuring optimal living conditions and minimizing stress-related health issues (Rajendran et al., 2023). Reproductive health monitoring is enhanced through the use of biosensors that track physiological indicators related to fertility and pregnancy. These sensors provide valuable insights into reproductive cycles, enabling better management of breeding programs (Halachmi et al., 2019). Smart sensors help optimize feeding schedules and nutrition plans by monitoring eating behaviors and nutritional intake. This data allows for the adjustment of feeding strategies to improve growth rates and overall health (Ronald and Raman, 2024).

3.3 Precision livestock farming

Precision livestock farming leverages data from smart sensors to allocate resources more efficiently. By analyzing health and environmental data, farmers can make informed decisions about resource distribution, enhancing productivity and sustainability (Iwasaki et al., 2019). Automation of health-related tasks is facilitated by smart sensors, which reduce the need for manual labor in monitoring and managing livestock health. This automation leads to cost savings and increased efficiency in farm operations. Smart sensors integrate with precision breeding programs by providing detailed health and genetic data. This integration supports the selection of optimal breeding pairs, improving the genetic quality and productivity of livestock (Go et al., 2022; Rahmawati et al., 2023)

4 Advantages of Using Smart Sensors

4.1 enhanced real-time monitoring capabilities

Smart sensors enable continuous data collection, providing a constant stream of information about livestock health. This capability allows for the monitoring of vital signs such as heart rate, temperature, and activity levels, which are crucial for early detection of health issues. The integration of IoT and wireless sensor networks facilitates the seamless collection and transmission of data, ensuring that farmers have access to real-time health insights (Rahmawati et al., 2023). The use of smart sensors allows for remote health management, enabling farmers to monitor livestock from distant locations. This is particularly beneficial for large-scale operations where physical presence is not always feasible. IoT platforms and cloud-based systems provide the infrastructure for remote monitoring, allowing data to be accessed and analyzed from anywhere. This reduces the need for frequent on-site visits and allows for more efficient farm management (Rajendran et al., 2023). Smart sensors are equipped with the capability to send immediate alerts when anomalies are detected in the health data of livestock. This feature is critical for prompt intervention, potentially preventing the escalation of health issues (Yazdanbakhsh et al., 2017). Automated notification systems integrated with smart collars or other wearable devices ensure that farmers and veterinarians are quickly informed of any irregularities.

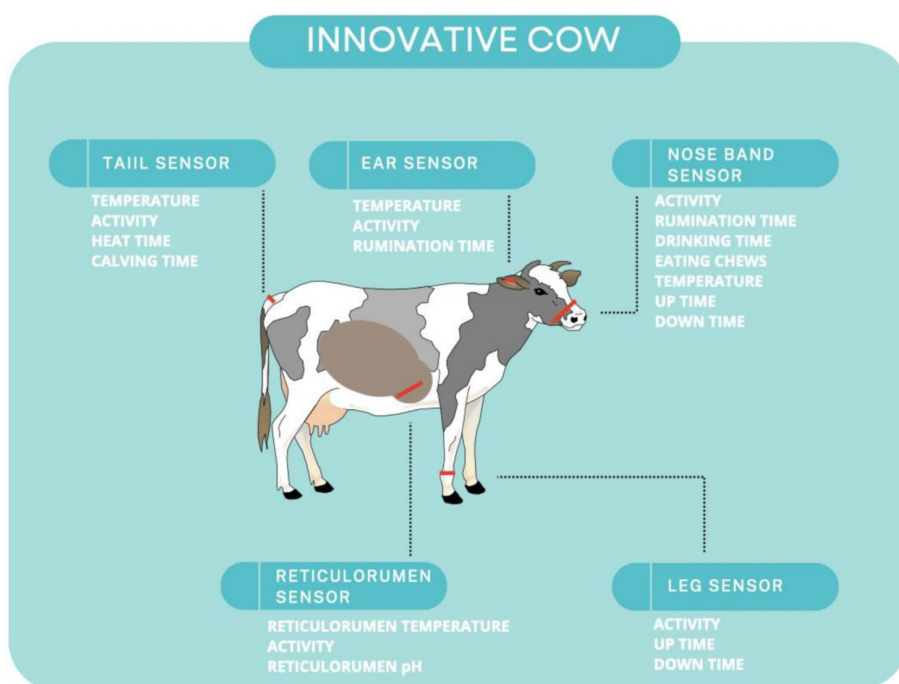


Figure 2 Innovative technologies applied to cows (Adopted from Džermeikaitė et al., 2023)

4.2 Cost-effectiveness in long-term livestock management

By enabling early detection of diseases and health issues, smart sensors help in reducing veterinary and medical expenses. Early intervention can prevent the need for more extensive and costly treatments, thus lowering overall healthcare costs for livestock (Džermeikaitė et al., 2023). The automation of health monitoring also reduces labor costs associated with manual health checks (Iwasaki et al., 2019). Smart sensors contribute to minimizing losses by ensuring timely detection and management of diseases, which in turn enhances productivity. By maintaining optimal health conditions, livestock can achieve better growth rates and production levels, reducing losses associated with disease outbreaks and poor productivity. Continuous health monitoring and early disease detection facilitated by smart sensors can lead to an extended lifespan for livestock. By maintaining better health and preventing severe illnesses, the overall longevity and productivity of the animals are improved, which is economically beneficial for farmers (Go et al., 2022).

4.3 Contribution to sustainable agriculture practices

Smart sensors help in reducing waste and optimizing the use of resources by providing precise data on livestock needs. This allows for more efficient feeding and resource allocation, minimizing waste and enhancing sustainability (Arshad et al., 2022). The data-driven approach ensures that resources are used effectively, contributing to more sustainable farming practices. The implementation of smart sensors supports eco-friendly farming practices by reducing the environmental impact of livestock farming. By optimizing resource use and reducing waste, these technologies help in lowering the carbon footprint of agricultural operations (Halachmi et al., 2019). The precision offered by smart sensors aligns with the goals of sustainable agriculture. Smart sensors play a role in supporting climate-smart agriculture by enabling adaptive management practices that respond to environmental changes. By providing real-time data on environmental conditions and livestock health, farmers can make informed decisions that align with climate-smart strategies (Ronald and Raman, 2024). This adaptability is crucial for maintaining productivity in the face of climate variability.

5 Challenges in Implementing Smart Sensors

5.1 Technological barriers

Connectivity remains a significant challenge in rural areas where livestock farms are typically located. The deployment of IoT technology for livestock monitoring often requires stable internet connections, which are not

always available in remote locations. This can hinder the real-time data transmission necessary for effective monitoring (Iwasaki et al., 2019). Power supply and battery management are critical for the continuous operation of smart sensors. Many farms lack the infrastructure to support constant power supply, making it necessary to rely on battery-powered devices. Efficient energy management systems are required to ensure that sensors remain operational over extended periods without frequent battery replacements (Rahmawati et al., 2023). The accuracy and reliability of sensors are crucial for effective livestock monitoring. Inaccurate data can lead to incorrect assessments of animal health, which can have serious implications. There is a need for ongoing calibration and validation of sensors to maintain their accuracy and reliability (Shohail et al., 2023).

5.2 Economic and logistical challenges

The initial investment required for implementing smart sensor systems can be prohibitive, especially for small and medium-sized farms. The cost of purchasing and installing IoT devices and sensors can be a significant barrier to adoption (Arshad et al., 2022). Maintaining and operating smart sensor systems require technical expertise and regular upkeep, which can be challenging for farmers who may not have the necessary skills or resources. This includes the need for regular software updates and hardware maintenance to ensure optimal performance (Rehman et al., 2022). Scalability is a concern for small and medium-sized farms that may not have the resources to expand their sensor networks as their operations grow. The systems need to be flexible and adaptable to different farm sizes and types (Halachmi et al., 2019).

5.3 Data-related concerns

Data privacy and security are major concerns when implementing IoT systems in livestock monitoring. The data collected by sensors can be sensitive, and there is a risk of unauthorized access or data breaches, which can compromise farm operations (Neethirajan, 2023). Interoperability between different sensor systems is essential for seamless data integration and analysis. Many farms use a variety of sensors from different manufacturers, which can lead to compatibility issues and hinder the effective use of data (Tangorra et al., 2024). The implementation of smart sensors generates large volumes of data that need to be processed and interpreted. This requires robust data management systems and analytical tools to convert raw data into actionable insights, which can be a complex and resource-intensive process (Rajendran et al., 2023).

6 Case Study: Implementation of Smart Sensors in Dairy Farms

6.1 Background of the selected case study

This case study focuses on a dairy farm located in a developing country, where the implementation of smart sensors aims to address challenges in livestock health monitoring and productivity. The farm is characterized by a large herd size, which necessitates efficient monitoring systems to manage animal health and optimize dairy production (Arshad et al., 2022). The farm deployed a variety of sensors, including cow collars equipped with temperature sensors, GPS modules, and heart rate monitors. These sensors are part of an intelligent system that integrates wireless sensor networks (WSNs) and the internet of things (IoT) to provide real-time health data and location tracking of the animals (Rahmawati et al., 2023). The primary objectives of implementing smart sensors on the farm were to enhance dairy production by improving animal health, reduce labor costs through automation, and provide early detection of diseases to prevent outbreaks. The system also aimed to support sustainable farming practices by optimizing environmental conditions for the livestock (Rajendran et al., 2023).

6.2 Outcomes and observations

The implementation of smart sensors led to significant improvements in animal health and productivity. The continuous monitoring of vital signs allowed for early detection of health issues, reducing morbidity and mortality rates. Additionally, the automation of environmental controls and feeding systems contributed to increased milk production and overall farm efficiency (Ronald and Raman, 2024). Several challenges were encountered during the deployment of smart sensors, including technical difficulties with sensor accuracy and data transmission, as well as resistance from farm workers accustomed to traditional methods. The integration of new technologies required training and adaptation to ensure effective use (Džermeikaitė et al., 2023). To address these challenges,

the farm implemented training programs for staff and invested in robust sensor technologies with improved accuracy and reliability. The use of IoT platforms facilitated better data management and analysis, leading to more informed decision-making. The experience highlighted the importance of stakeholder engagement and continuous system evaluation.

Table 1 Early detection of diseases; developing a model in one farm and validating it in another farm (Adopted from Halachmi et al., 2019)

Farm	Correct
1	83%
2	70%
3	91%
4	67%
5	77%

6.3 Broader implications for livestock health monitoring

The success of the smart sensor implementation in this case study suggests a high potential for replication in other regions, particularly in developing countries where similar challenges exist. The scalability of IoT-based systems makes them suitable for various farm sizes and conditions (Iwasaki et al., 2019). The insights gained from this implementation can inform policy and regulation development by demonstrating the benefits of technology in livestock management. Policymakers can use these findings to promote the adoption of smart farming technologies and support infrastructure development (Halachmi et al., 2019). The case study provides valuable insights for future technological advancements in livestock health monitoring. It underscores the need for continuous innovation in sensor technology, data analytics, and system integration to enhance the effectiveness and efficiency of smart farming solutions (Go et al., 2022).

7 Future Directions

7.1 Emerging technologies in smart livestock monitoring

The integration of internet of things (IoT) technology in livestock monitoring is transforming traditional farming practices. IoT-enabled devices facilitate remote data collection and control, enhancing precision in livestock management. These devices include sensors, actuators, and communication protocols that enable real-time monitoring of animal health and behavior (Terence et al., 2024). The use of wearable IoT devices is particularly promising, offering precise perception and sustainability monitoring, although their adaptation for farm animals is still in its nascent stages (Zhang et al., 2021). Artificial intelligence (AI) and machine learning are pivotal in processing the vast amounts of data generated by IoT devices (Chen, 2024; Huang and Lin, 2024). These technologies enable predictive analytics, allowing for early disease detection and improved decision-making in livestock management. AI-driven systems can analyze complex datasets to identify patterns and trends, thereby enhancing the efficiency and effectiveness of livestock health monitoring (Džermeikaitė et al., 2023). Bio-sensing technologies are advancing rapidly, offering new frontiers in animal health management. These include wearable sensors and biosensors that can monitor various health parameters such as body temperature, rumination, and disease biomarkers. The development of nanosensors and advanced diagnostic tools is crucial for real-time health monitoring and early disease detection in livestock.

7.2 Strategies for overcoming current challenges

To make smart livestock monitoring technologies more accessible, there is a need to focus on cost-effective solutions. Innovations in IoT and wearable technologies can reduce production costs and make these tools more affordable for farmers (Church and Bork, 2023). The use of low-power wide-area networks (LPWANs) like LoRaWAN® can also help in reducing operational costs while maintaining efficient data transmission (Behjati et al., 2021). Establishing robust networks for data sharing is essential for the success of smart livestock monitoring systems. This involves developing secure and scalable IoT infrastructures that facilitate seamless data exchange

between devices and stakeholders (Farooq et al., 2022). Collaborative security models are also necessary to address data privacy and security concerns. Training and capacity building are critical to ensure that farmers can effectively utilize smart technologies. Providing education and resources to farmers will enable them to integrate these technologies into their daily operations, thereby improving livestock management and productivity (Caria et al., 2019).

7.3 Policy and collaborative frameworks

Government support through policies and incentives can accelerate the adoption of smart livestock monitoring technologies. This includes funding for research and development, subsidies for technology adoption, and the establishment of regulatory frameworks that support innovation. Collaborations between industry and academia are vital for advancing research and development in smart livestock monitoring. These partnerships can drive innovation, facilitate knowledge exchange, and lead to the development of cutting-edge technologies that address current challenges in livestock health monitoring (Neethirajan, 2019). Global initiatives aimed at standardizing the use of smart sensors in livestock monitoring can ensure consistency and interoperability across different systems. Such initiatives can also promote best practices and facilitate the global exchange of knowledge and technology (Neethirajan, 2017).

Acknowledgments

We are grateful to Mrs. Guo for critically reading the manuscript and providing helpful comments that improved the clarity of the text.

Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

References

- Arshad J., Rehman A., Othman M., Ahmad M., Tariq H., Khalid M., Moosa M., Shafiq M., and Hamam H., 2022, Deployment of wireless sensor network and IoT platform to implement an intelligent animal monitoring system, *Sustainability*, 14(10): 6249.
<https://doi.org/10.3390/su14106249>
- Behjati M., Noh A., Alobaidy H., Zulkifley M., Nordin R., and Abdullah N., 2021, LoRa Communications as an enabler for internet of drones towards large-scale livestock monitoring in rural farms, *Sensors*, 21(15): 5044.
<https://doi.org/10.3390/s21155044>
- Caria M., Sara G., Todde G., Polese M., and Pazzona A., 2019, Exploring smart glasses for augmented reality: a valuable and integrative tool in precision livestock farming, *Animals*, 9(11): 903.
<https://doi.org/10.3390/ani9110903>
- Chen T., 2024, Artificial intelligence and drug design: future prospects and ethical considerations, *Computational Molecular Biology*, 14(1): 9-19.
<https://doi.org/10.5376/cmb.2024.14.0002>
- Church J., and Bork E., 2023, 66 Emerging precision ranching technology is enabling the development of a “smart” biome, *Journal of Animal Science*, 101(Supplement_3): 140-141.
<https://doi.org/10.1093/jas/skad281.171>
- Džermeikaitė K., Bačėninaitė D., and Antanaitis R., 2023, Innovations in cattle farming: application of innovative technologies and sensors in the diagnosis of diseases, *Animals*, 13(5): 780.
<https://doi.org/10.3390/ani13050780>
- Farooq M., Sohail O., Abid A., and Rasheed S., 2022, A survey on the role of iot in agriculture for the implementation of smart livestock environment, *IEEE Access*, 10: 9483-9505.
<https://doi.org/10.1109/ACCESS.2022.3142848>
- Go A., Reyes B., Lii J., Alipio M., Hall S., and Evanoso J., 2022, A taxonomy of intelligent wearable devices and biosensors for cattle health monitoring, 2022 37th International Technical Conference on Circuits/Systems, Computers and Communications (ITC-CSCC), IEEE, 2022: 403-406.
<https://doi.org/10.1109/ITC-CSCC55581.2022.9895086>
- Halachmi I., Guarino M., Bewley J., and Pastell M., 2019, Smart animal agriculture: application of real-time sensors to improve animal well-being and production, *Annual Review of Animal Biosciences*, 7: 403-425.
<https://doi.org/10.1146/annurev-animal-020518-114851>
- Huang J., and Lin X.F., 2024, Advances in animal disease resistance research: discoveries of genetic markers for disease resistance in cattle through GWAS, *Bioscience Evidence*, 14(1): 24-31.
<https://doi.org/10.5376/be.2024.14.0004>

- Iwasaki W., Morita N., and Nagata M., 2019, IoT sensors for smart livestock management, chemical, gas, and biosensors for internet of things and related applications, Elsevier, 2019: 207-221.
<https://doi.org/10.1016/b978-0-12-815409-0.00015-2>
- Neethirajan S., 2017, Recent advances in wearable sensors for animal health management, *Sensing and Bio-sensing Research*, 12: 15-29.
<https://doi.org/10.1016/J.SBSR.2016.11.004>
- Neethirajan S., 2019, 2 Biosensors - new frontiers in animal welfare, *Journal of Animal Science*, 97(Suppl 2): 2.
<https://doi.org/10.1093/JAS/SKZ122.002>
- Neethirajan S., 2023, SOLARIA-SensOr-driven resiLIent and adaptive monitoRIng of farm animals, *Agriculture*, 13(2): 436.
<https://doi.org/10.3390/agriculture13020436>
- Rahmawati D., Ms A., Faradhilah N., Alfita R., Nahari R., and Setiawan H., 2023, Design of a real time cow smart collar health and position monitoring system, 2023 IEEE 9th Information Technology International Seminar (ITIS), IEEE, 2023: 1-7.
<https://doi.org/10.1109/ITIS59651.2023.10420353>
- Rajendran J., Alagarsamy M., Seva V., Dinesh P., Rajangam B., and Suriyan K., 2023, IoT based tracking cattle healthmonitoring system using wireless sensors, *Bulletin of Electrical Engineering and Informatics*, 12(5): 3086-3094.
<https://doi.org/10.11591/eei.v12i5.4610>
- Rehman A., Arshad J., Sadiq M., Rehman A., Ahmad M., Hasan Z., Hamadi H., and Faiz T., 2022, Implementation of an intelligent animal monitoring system using wireless sensor network and IoT platform, 2022 International Conference on Cyber Resilience (ICCR), IEEE, 2022: 1-11.
<https://doi.org/10.1109/ICCR56254.2022.9996080>
- Ronald B., and Raman R., 2024, Multi-sensor fusion in livestock with iot for biometric sensing and MQTT for enhanced health insights, 2024 2nd International Conference on Disruptive Technologies (ICDT), IEEE, 2024: 935-940.
<https://doi.org/10.1109/ICDT61202.2024.10489625>
- Sahoo G., Devrani R., and Aadil M., 2024, Enhancing efficiency in livestock monitoring and management with IoT solutions', 2024 International Conference on Optimization Computing and Wireless Communication (ICOCWC), IEEE, 2024: 1-7.
<https://doi.org/10.1109/ICOCWC60930.2024.10470611>
- Schulthess L., Longchamp F., Vogt C., and Magno M., 2023, A lora-based and maintenance-free cattle monitoring system for alpine pastures and remote locations, *Proceedings of the 11th International Workshop on Energy Harvesting and Energy-Neutral Sensing Systems*, 2023: 44-50.
<https://doi.org/10.1145/3628353.3628549>
- Shohail K.I., Awsaf W., and Ali M.T., 2023, Livestock health management system using advance technology, 26th International Conference on Computer and Information Technology (ICCIT), IEEE, 2023: 1-6.
<https://doi.org/10.1109/ICCIT60459.2023.10441605>
- Stygar A., Gómez Y., Berteselli G., Costa D., Canali E., Niemi J., Llonch P., and Pastell M., 2021, A systematic review on commercially available and validated sensor technologies for welfare assessment of dairy cattle, *Frontiers in Veterinary Science*, 8: 634338.
<https://doi.org/10.3389/fvets.2021.634338>
- Tangorra F., Buoio E., Calcante A., Bassi A., and Costa A., 2024, Internet of things (IoT): sensors application in dairy cattle farming, *Animals*, 14(21): 3071.
<https://doi.org/10.3390/ani14213071>
- Terence S., Immaculate J., Raj A., and Nadarajan J., 2024, Systematic review on internet of things in smart livestock management systems, *Sustainability*, 16(10): 4073.
<https://doi.org/10.3390/su16104073>
- Yazdanbakhsh O., Zhou Y., and Dick S., 2017, An intelligent system for livestock disease surveillance, *Information Sciences*, 378: 26-47.
<https://doi.org/10.1016/j.ins.2016.10.026>
- Zhang M., Wang X., Feng H., Huang Q., Xiao X., and Zhang X., 2021, Wearable internet of things enabled precision livestock farming in smart farms: a review of technical solutions for precise perception, biocompatibility, and sustainability monitoring, *Journal of Cleaner Production*, 312: 127712.
<https://doi.org/10.1016/J.JCLEPRO.2021.127712>

Disclaimer/Publisher's Note



The statements, opinions, and data contained in all publications are solely those of the individual authors and contributors and do not represent the views of the publishing house and/or its editors. The publisher and/or its editors disclaim all responsibility for any harm or damage to persons or property that may result from the application of ideas, methods, instructions, or products discussed in the content. Publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.