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Robotic Livestock Breeding: A Historical and Technological Review

Robotik Hayvan Yetiştiriciliği: Tarihsel ve Teknolojik Bir Derleme

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ABSTRACT

The development of robotic livestock farming reflects the rapid integration of artificial intelligence (AI), automation, and Internet of Things (IoT) technologies into modern agriculture. This review explores the historical evolution of robotic systems in animal farming, highlighting key milestones from early mechanization to advanced AI driven management tools. Twelve major technological domains are described, including robotic milking, feeding, reproductive assistance, climate control, and autonomous herd management. The review also evaluates the advantages, challenges, and future directions of robotic livestock systems, emphasizing sustainability, productivity, and animal welfare.

Keywords: AI; Animal wefare; IoT; Reproductive assistance; Robotic livestock

ÖZET

Robotik hayvancılık çiftçiliğinin gelişimi, yapay zeka (AI), otomasyon ve Nesnelerin İnterneti (IoT) teknolojilerinin modern tarıma hızla entegre edilmesini yansıtır. Bu inceleme, erken mekanizasyondan gelişmiş AI destekli yönetim araçlarına kadar önemli kilometre taşlarını vurgulayarak, hayvancılıkta robotik sistemlerin tarihsel evrimini inceler. Robotik sağım, besleme, üreme yardımı, iklim kontrolü ve otonom sürü yönetimi dahil olmak üzere on iki önemli teknolojik alan açıklanmaktadır. İnceleme ayrıca robotik hayvancılık sistemlerinin avantajlarını, zorluklarını ve gelecekteki yönlerini değerlendirerek sürdürülebilirlik, üretkenlik ve hayvan refahını vurgular.

Anahtar Kelimeler: AI: Hayvan refahı; IoT; Robotik hayvancılık; Üreme yardımı

1. INTRODUCTION

Aristotle (384–323 BC) once said, “If every tool could work by itself, by appropriate command or in a predetermined way then there would be no need for workers or slaves.” This early philosophical insight significantly anticipates our current era, in which autonomous tools, powered by robotics and artificial intelligence (AI) are increasingly replace the need for human labor. Yet robotics progressed slowly until the Industrial Revolution, and was only marginally developed by modern standards until the 13th century. One notable exception is the work of Ismail al-Jazari (1136 Upper Mesopotamia, 1206 Cizre), who is generally considered the father of cybernetics but is not widely recognized in Western scientific discourse. Al-Jazari laid out the basic principles of cybernetics, the field concerned with the control and regulation of complex systems, both living and nonliving. He is credited with designing and operating what can be considered the first robot, and his work is believed to have influenced Leonardo da Vinci (1452-1519) (Ciurea and Bratu, 2022). Living in the Cizre and Diyarbakır regions, Al-Jazari documented approximately 50 mechanical devices and instructions for their construction (Cora and Şahin, 2020). Today, the field of robotics has advanced rapidly. One important application area is robotic animal husbandry, often described as the “farming of the future” through the lens of artificial intelligence. This field integrates robotics, AI-enabled systems, sensors, automation, and the Internet of Things (IoT) into livestock management to improve animal welfare, reduce labor demands, and increase overall productivity.

1.1. History of robotic animal husbandry

Robotic animal husbandry refers to the use of technology in the animal husbandry sector to increase efficiency, reduce labor, and improve animal health. Robotic animal husbandry is directly related to the history of technology use in animal husbandry. This process began in the mid-20th century in parallel with the modernization of agriculture and animal husbandry and has gone through many stages to date. Developments in this field have evolved in parallel with technological advances (Rankin et al., 2017).

Development of robotic animal husbandry from past to present

1. 1.1. First mechanization (1900-1950)

In the early 20th century, with the widespread use of agricultural machinery, the first mechanical devices began to be used in the animal husbandry sector. The aim was to reduce manpower and increase hygiene in milking. In 1907, the first automated milking machine was developed. This is considered the beginning of mechanization in animal husbandry.

1.1.2. Early period (1950 - 1980)

After World War II, automation technologies developed rapidly and animal husbandry equipment was also modernized in this process. In the 1950s, milking lines began to be used on large farms. Automatic feeding machines were developed to ensure regular feeding of animals. During this period, mechanical systems began to be used, albeit limited, to monitor the health and productivity of animals. The first robotic applications began in the mid-20th century, but this was a period when technology was just beginning to be adapted to agriculture. In animal husbandry, milking, feeding and care processes, which were generally carried out with manual labor, continued. Technological developments began to provide infrastructure for agricultural machines and robots. However, the use of robots in animal husbandry was limited during this period. Functions such as milking could be done with only a few agricultural machines, but these machines still relied on human intervention.

1.1.3. First robotic systems and trials, the birth of robotic milking (1980-1990)

In the late 1980s, the first robotic milking systems were developed in the Netherlands. The 1990s were a period when robotic technologies began to be used more in the agricultural sector, and significant developments took place. The aim was to milk animals according to their individual needs and to save labor by minimizing human intervention. In 1992, Lely launched the first commercial milking robot, the Lely Astronaut (Elischer et al., 2013). This system achieved the first major commercial success that made milking autonomous and found widespread use in the world. Moreover, robotic feeding systems also began to develop thanks to the robotic developments in the animal husbandry sector in these years. During this period, feeding robots equipped with sensors began to be used so that animals could receive their feed in the right amount and at the right time. Health monitoring systems began to develop; possible health problems could be detected by monitoring the movements, temperatures and feed consumption of animals.

1.1.4. The period of accelerating technological progress (2000 - 2010)

GPS, RFID (Radio Frequency Identification) and sensor technologies began to be used in animal husbandry in the 2000s. This process marks a period when robotic animal husbandry developed rapidly and found a wider area of application. Systems were developed to monitor the movements, health status and reproductive cycles of animals. It became widespread in countries such as Australia and the USA, especially to reduce losses in large herds. During this period, feeding robots began to be used on farms to automatically adjust the diets of animals.

Robotic systems such as the Lely Astronaut and DeLaval VMS began to be used on more farms around the (Sorensen et al., 2016) world. This was a significant turning point in the automation of milking. Robots began to be used to perform cleaning functions in animal shelters. These robots reduced manpower by performing tasks such as manure removal. Thanks to smart sensors and AI-supported algorithms, the health status of animals began to be monitored more precisely. Robotic systems were developed for egg collection, incubation and chick care in poultry farming. Robots began to make more sophisticated decisions by being integrated with AI algorithms. For example, feeding and watering systems could be adjusted according to the individual needs of animals. Robots and AI began to monitor the reproductive processes of animals and assist in artificial insemination and genetic improvement processes. Robots began to be used for autonomous management and herding of herds. These robots can monitor the movements of animals and direct them when necessary. Robots that monitor animal behavior provide more precise data by analyzing the health status of each individual, their feeding habits and their reactions to environmental factors.

1.1.5. Artificial intelligence and IoT integration (2010 - 2020)

Artificial intelligence-supported systems that analyze animal behavior and diagnose health care early. For example, software that detects stress solutions and possible symptoms of adaptations has emerged. Devices, sensors and robots used in barns have been integrated with the internet, allowing remote management. Farm management has become widespread through mobile applications. Autonomous shepherd robots and drones have begun to develop large herds of animals.

1.1.6. Modern era (2020s and beyond)

In recent years, robotic animal husbandry has developed further with the combination of technologies such as artificial intelligence, machine development and IoT (Internet of Things). Energy-efficient robotic systems and environmentally friendly manure management systems. Robotic technologies have begun to be used in reproductions such as artificial insemination and embryo transfer. Robotic animal husbandry technologies have begun to expand in regional developments such as the Netherlands, Germany and the USA. Smart animal barns that combine climate control, automatic feeding and health systems.

1.2. The basic technologies of robotic animal husbandry

1.2.1. Automatic milking systems technology

In this technology, animals are recognized by the RFID chip on their horns or feet. Radio Frequency Identification technology is a method of recognizing objects individually and automatically using radio frequency. Robots increase efficiency and reduce animal stress by milking cows at certain intervals. This technology is widely used in countries such as Germany and New Zealand.

Example: Systems such as Lely Astronaut (Elischer et al., 2013) and DeLaval VMS (Sorensen et al., 2016) completely automate milking and save farmers time while monitoring animal health.

- Cows go to the milking robots themselves and the robots perform the milking.
- The milk yield, time of milking and health status of each animal are monitored with sensors.
- Cows enter the area designated for milking.
- The robot recognizes the cow's teats with sensors and milks in the correct position.
- After milking, the robot records the amount of milk, milking duration and milking frequency for each cow. It shows milk yields daily, monthly and yearly both graphically and as data to the user.
- The animal's health and udder health are also monitored during milking.

1.2.2. Automatic feeding systems technology

Smart feeding robots prevent waste and ensure better growth by determining the amount of feed according to the needs of the animals. These robots are actively used on many farms in Sweden.

Example: Systems such as GEA MixFeeder (Nielsen et al., 2018) and Trioliet (Vaintrub et al., 2021) automatically distribute feed and ensure that all animals on the farm are adequately fed.

- Robots reduce feed waste by determining the amount of feed and distribution time according to the needs of the animals.
- The feed needs of the animals are determined by sensors. The user of the system determines the amount of feed and ration that animals should consume. Sensors recognize the animal and are used to transfer the defined amount to the feeder, waterer or nursing container for the animal approaching the feed unit.

• The robots give the right amount of feed to each animal individually.

• Feeding times and amounts can be adjusted according to factors such as the age, breed and health status of the animal.

• The systems monitor and optimize feed consumption.

1.2.3. Behavior and health monitoring systems technology

Robots equipped with sensors monitor the movements, eating behaviors and health status of the animals using drones, GPS and artificial intelligence. In addition, wearable sensors and IoT devices attached to the animals' bodies are used to constantly monitor their health status. In abnormal situations, an early warning system is activated. Especially in countries with large herds such as Australia and the USA, these technologies are used to diagnose animal diseases early and reduce losses. In addition, systems called Drone Shepherd (shepherd drone) are common in Australia.

Example: Systems such as CowManager (Zambelis et al., 2019) and Fitbit (Gabel, 2018) for Cows collect animal health data and provide analyses to farmers to make efficient decisions.

• Sensors attached to animals collect data such as movement, temperature, feed consumption and detect possible disease symptoms at an early stage.

• Artificial intelligence-supported algorithms send notifications to farmers in abnormal situations.

• Sensors attached to animals collect biometric data such as movement, body temperature, heart rate, and respiratory rate.

• Artificial intelligence and machine learning algorithms analyze this data and detect disease symptoms or abnormal behavior early.

• Reports are sent to farmers about the animal's health status.

1.2.4. Reproductive systems technology

Robots can be used in processes such as artificial insemination, embryo transfer and genetic improvement. The body temperature and hormonal changes of animals are monitored with IoT sensors. AI algorithms analyze the data and detect the estrus period. The use of artificial insemination and embryo transfer robots is quite common in cattle farms, especially in the USA.

Example: Robotic systems that monitor the genetic characteristics of animals, such as Sexing Technologies, reveal the genetic characteristics of animals. While SCR Heatime detects estrus, SenseTime can monitor reproduction in cattle (Dos Santos, 2022).

• Robotic reproductive systems automate processes such as artificial insemination and embryo transfer. Genetic monitoring systems monitor the genetic potential of animals and offer improvement strategies.

• Reproductive processes such as artificial insemination and embryo transfer can be performed more quickly and precisely with the help of robots and automatic devices.

• Artificial insemination and embryo transfer are performed by robots.

• Genetic data is collected to evaluate the health and productivity potential of animals.

1.2.5. Climate controlled shelter systems technology

Smart air conditioning systems provide a healthier environment by reducing animal stress. For example, in climate controlled shelters in the Netherlands, humidity and temperature levels are automatically regulated to ensure animal comfort.

Example: Robotic systems that provide climate control in Big Dutchman chicken (Zhou et al., 2023) and pig farms and SKOV cattle and poultry farms (Dilaver and Dilaver, 2024).

• Radiant heaters are used in cold climates, and fans and evaporative coolers are used in hot climates.

• Carbon dioxide, ammonia and humidity levels are controlled with mechanical ventilation support.

1.2.6. Autonomous cleaning robots technology

These are systems where robots that clean manure are used to ensure hygiene in barns. In this way, the health of animals is improved and labor is reduced.

Example: Cleaning robots such as JOZ Barn Cleaner and Lely Discovery (Ebertz et al., 2019) are used for barn cleaning and disinfection processes.

• Robots collect and clean manure in barns.

• Some robots automatically collect and carry manure, while others distribute manure to a specific area and offer it for use as organic fertilizer.

1.2.7. Robotic incubation and egg collection systems technology

In these systems, egg collection, incubation and chick care processes in poultry farming are automated with robots. Thanks to their technology, they ensure that eggs are collected without damage and that incubation conditions are optimized.

Example: Companies such as Rockwell Automation, Big Dutchman, Egg-Collecting Robot by Novatech (Ozenturk et al., 2023) have developed such robotic incubation and egg collection systems.

- The eggs laid by the chickens are detected by robotic systems with sensors.
- The sensors determine the location of the eggs and direct the robots to the right place.
- The quality control of the eggs is carried out and they are classified according to their size.

1.2.8. Automatic water supply systems technology

These systems, which measure the water requirement with the help of sensors, also ensure that the animals receive regular and sufficient amounts of water. In this way, water waste is prevented. There are special water supply systems for chickens, cows and other farm animals.

Example: Water supply systems such as Big Dutchman Nipple Drinker System, Cowmatic Automatic Drinking System (Kraim and Çay, 2023), Dairy Master Automated Water System (Grinter et al., 2019) prevent waste by meeting the water needs of the animals correctly.

- The water distribution network and pipes are under the control of these systems.
- Water quantity and quality are determined with sensors and detection systems.
- Measurements are made with temperature and pH sensors.
- Water flow is programmed with timers.

1.2.9. Pregnancy tracking and early miscarriage detection technology

This technology, where the pregnancy status of animals can be tracked with ultrasound imaging and biosensors, can also process the data and detect miscarriage risk or complications at an early stage.

Example: Ai-Medical Vet AI and Fujitsu AI are technologies that can determine the pregnancy status of cattle with ultrasound data (Džermeikaitė et al., 2023).

- Artificial intelligence analyzes ultrasound images to determine whether there is a pregnancy.
- Body temperature, activity level and hormone changes are monitored.

• It sends a warning when an abnormal situation such as miscarriage risk is detected.

1.2.10. Smart fence systems technology

In this technology, smart fences and GPS-based systems are used to ensure that animals stay in a certain area. These systems monitor the location of the animals and give a warning when necessary.

Example: Systems such as Premier 1 Supplies, Geofence, Tractive GPS Tracker Systems (Hofmann et al., 2022), Systems are used to ensure the safety of animals and manage the boundaries of the lands by integrating with different technologies.

• Sensors monitor the movement of animals

• It provides the breeder with the opportunity for remote monitoring and control.

• It gives an alarm when the animal crosses the borders and sends a notification to the breeder via the mobile application.

1.2.11. Autonomous herd management robots technology

Autonomous herd management robots are used to direct animals such as sheep, cows or cattle. These robots keep the herd in a certain area and allow the animals to go to food or water areas.

Example: AgBot: These are autonomous robots used in agriculture and designed to direct herds (Kamboj et al., 2022).

• Robots follow animals using GPS and sensors and direct the herd correctly.

• Robots that direct the herd when necessary keep the animals in designated areas.

1.3. Overview of key studies in robotic animal husbandry

The development and integration of robotic systems in livestock farming have gained significant momentum over the last two decades, leading to species-specific advancements in automation, monitoring, and welfare enhancement. Particularly in dairy cattle farming, robotic milking systems and health monitoring technologies have become well-established, with studies such as those by Løvendahl and Sørensen (2016) and Rutten et al. (2013) emphasizing their effectiveness in improving both productivity and animal welfare. In contrast, robotic systems in small ruminants (sheep and goats) are less mature but rapidly evolving, focusing on areas like automatic weighing, behavioral monitoring, and precision feeding. Research in poultry farming, as reported by Ozger et al. (2024) and Campbell et al. (2024), highlights high levels of automation in environmental control, health tracking, and production monitoring due to the sector's suitability for large-scale implementation. The main studies on robotic animal husbandry in large ruminant breeding (Table 1), small ruminant breeding (Table 2), and poultry breeding (Table 3) were presented below, respectively.

Table 1. Literature on robotic systems in large ruminant breeding

No	Topic	Summary	Reference
1	Lameness detection	Early detection of lameness using force platforms and robotic systems	Pastell et al., 2006
2	Sensor data fusion	Integration of multiple sensor inputs for animal health and welfare analytics	Rutten et al., 2013
3	Precision livestock farming	Use of sensors and robotics for welfare monitoring in intensive cattle systems	Berckmans, 2014
4	RFID-based herd management	Animal tracking and feed management using automatic identification systems	Caja et al., 2016
5	Transition to automated milking systems	Organizational and behavioral challenges in switching from conventional to robotic milking	Tse et al., 2017
6	IoT and environmental monitoring	Monitoring temperature, humidity, and gas levels in barns using sensors	Ozger et al., 2024
7	Robotic milking systems	Impact of robotic milking on labor efficiency and milk quality	Meijer et al., 2020
8	Robotic manure removal	Environmental and hygiene benefits of autonomous manure management systems	Dilaver and Dilaver., 2024
9	Behavior analysis with	AI Application of machine learning to monitor behavior changes in dairy cows.	Wagner et al., 2020

Table 2. Literature on robotic systems in small ruminant breeding

No	Topic	Summary	Reference
1	Automatic milk recording (goats)	Use of electronic ID and robotics for individual milk yield tracking	Caja et al., 2014
2	RFID in small ruminants	Identification and feed intake monitoring in flocks using RFID	Cappai et al., 2014
3	IoT applications in large ruminants	Local sensor-based monitoring of body temperature, feed intake, and location	Tangorra et al., 2024
4	Semi-autonomous shepherd robots	Land-based robotic systems for guiding sheep flocks	Long et al., 2020
5	Movement tracking in goats	Integration of GPS and accelerometers in precision shepherding systems	Chebli et al., 2022
6	Automatic weighing systems	Real-time weight monitoring using electronic platforms	Bate et al., 2023
7	Welfare monitoring in sheep	Use of cameras and accelerometers to monitor behavior and health	Alvarenga et al., 2016

Tablo 3. Literature on robotic systems in poultry breeding

No	Topic	Summary	Reference
1	Anomaly detection in poultry	Identification of health-related behaviors via video processing	Bhuiyan and Wree, 2023

2	Vision-based welfare monitoring	AI-based analysis of poultry behavior using video cameras	Campbell et al., 2024
3	Environmental control systems	Robotic systems and sensors for maintaining indoor climate	Usher et al., 2017
4	Automated feeding systems	Sensor-based control of poultry feeding mechanisms	Chaurasia, 2024
5	Robot-assisted health inspection	Mobile robots for health surveillance in broiler houses	Ozentürk et al., 2024
6	Flock behavior monitoring	Classification of abnormal behavior using visual and acoustic sensors	Sun et al., 2024
7	Laser-guided flock management	Using robotic systems and laser lights to direct poultry movement	Ozentürk et al., 2024

1.4. Advantages and disadvantages of robotic animal husbandry

Robotic systems have become a cornerstone of precision livestock farming, aiming to enhance productivity, reduce labor intensity, and promote animal welfare through the integration of artificial intelligence, sensor technologies, and automation (Rutten et al., 2013). These technologies enable continuous monitoring and data-driven decision-making, which significantly improve management efficiency in livestock operations (Caja et al., 2016). In particular, robotic milking systems, automated feeding, health monitoring, and climate control mechanisms have proven especially beneficial in large-scale dairy and poultry farms (Sørensen et al., 2020). However, despite their advantages, robotic animal husbandry systems also pose several limitations, including high initial investment costs, dependency on stable infrastructure, and challenges in integration for small-scale operations (Berckmans, 2014; Banhazi et al., 2012). Furthermore, concerns regarding data security, technical literacy among farmers, and potential negative impacts on animal behavior necessitate critical evaluation before implementation. The tables below provide a comparative summary of the main advantages (Table 4) and disadvantages and challenges (Table 5) of robotic animal husbandry systems, based on current literature.

Table 4. Advantages of robotic animal husbandry

Advantage	Explanation
Increased Efficiency	Automates repetitive tasks, increases productivity
Enhanced Sustainability	Supports environmentally friendly practices and resource optimization
Improved Animal Health Monitoring	Allows real-time monitoring of animal health via sensors and AI-based systems
Labor Reduction	Decreases the need for manual labor, reducing human workload
Precision Livestock Farming	Enables data-driven decisions for feeding, reproduction, and health management

Potential for Full Autonomy	Paves the way for fully autonomous farm operations
Technological Integration	Combines AI, IoT, and big data for intelligent farm management
Better Adaptation in Large-Scale Farms	More effective and economically viable in high-capacity operations
Nutrition Optimization	AI can formulate optimized feeding plans tailored to each animal's needs
Reduced Carbon Footprint	Contributes to environmentally sustainable production systems

Table 5. Disadvantages of robotic animal husbandry

Disadvantage / Challenge	**Explanation**
Technical Knowledge Requirement	Requires farmers to be familiar with advanced technology; lack of training can hinder usage
System Failures and Maintenance Needs	Malfunctions can halt production and require costly repairs or interventions
Dependence on Electricity and Internet	Continuous operation depends on stable energy and connectivity infrastructure
Data Management and Security Risks	Collected data must be securely stored, managed, and interpreted correctly
High Initial Investment Cost	Installation and maintenance costs can be prohibitive, especially for small-scale farmers
Labor Displacement	Traditional jobs may be reduced or eliminated, raising social and economic concerns
Poor Suitability for Small Farms	High costs and integration complexity can threaten smallholder farm sustainability
Long-Term ROI	Financial return on investment may take years, making it less attractive for short-term planning
Environmental and Climatic Limitations	Extreme weather conditions may negatively affect system performance and reliability
Potential Impact on Animal Behavior	Excessive monitoring or automation may disrupt natural animal behaviors or cause stress

1.5. Robotic animal husbandry today and in the future

Today, dairy cows are the species best adapted to robotic milking systems and health monitoring systems. Poultry is the species most suitable for large-scale automation. Pigs and small cattle are the species that benefit the most from robotic systems in terms of herd management and health monitoring. If we need to choose the most suitable species in terms of efficiency and technology adaptation among these species, dairy cattle are the most advantageous. However, it is also a fact that poultry farming is the most suitable species for applications in terms of automation.

Robotic animal husbandry is a rapidly developing field and has great potential in terms of efficiency, sustainability and animal welfare. Today, robotic systems are becoming increasingly widespread in both large-scale and small-scale farms. AI, IoT and big data analysis are effectively used in every area of animal husbandry. It is expected that fully autonomous farms will become widespread in the future. More sustainable, environmentally friendly systems that prioritize animal welfare are being developed. It is possible for robotic technologies to reach a wider user base at low costs.

Robotic animal husbandry has undergone a long evolution from mechanical devices in the early 20th century to autonomous systems supported by artificial intelligence and IoT. This process is constantly evolving to increase the efficiency of farms, reduce their costs and improve animal welfare. Today, robotic animal husbandry is creating a revolutionary transformation in the agricultural sector.

With developing technology, the following innovations are expected to be more common in robotic animal husbandry in the future:

- Nutrition optimization with artificial intelligence
- Data-based and intelligent farm management
- Autonomous herd management systems
- Robotic breeding solutions for genetic improvement
- Artificial intelligence-supported decision systems for animal welfare
- Carbon Footprint Reduction and Sustainability

It is thought that a more sustainable and efficient animal husbandry strategy will be possible in the future thanks to these technologies. Robotic animal husbandry systems are a technology that responds to the greatest needs of modern animal husbandry. With both economic and environmental benefits, they will be used more widely in the future and will continue to revolutionize the animal husbandry sector. These systems are especially suitable for large-scale farms.

2. CONCLUSION AND RECOMMENDATIONS

The evolution of robotic animal husbandry reflects a broader transformation in agriculture, driven by rapid advances in artificial intelligence, automation, and the Internet of Things (IoT). From early mechanized milking machines to today's autonomous, sensor driven systems, each technological milestone has contributed to reshaping livestock farming. Modern robotic systems now manage essential processes such as milking, feeding, reproduction, health monitoring, and environmental control with increasing precision and minimal human intervention. These innovations have significantly improved productivity, enhanced animal welfare, and reduced labor dependency on farms.

However, despite these advantages, the implementation of robotic technologies is not without challenges. High initial investment costs, the need for technical expertise, data security concerns, and the variability of success across different species and farm scales remain critical barriers. Furthermore, ethical considerations related to animal behavior, natural living conditions, and long-term reliance on automation must be carefully evaluated.

Looking forward, the integration of AI driven analytics, real time monitoring, and machine learning algorithms will likely lead to even smarter and more adaptive livestock systems. Research and development efforts should prioritize not only technical efficiency but also ecological sustainability and the ethical implications of fully automated animal farming. Ultimately, robotic animal husbandry is poised to play a central role in shaping the future of sustainable, high-welfare livestock production in an increasingly digital agricultural landscape.

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