

How Technology Plays a Role in Livestock Management and Monitoring

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Abstract

The purpose of this research is to investigate three technologies — automated feeding systems, electronic ear tags, and digital twins with the Internet of Things — for monitoring and managing livestock operations of all sizes and their impacts on the United Nations Sustainable Development Goals: Industry, Innovation, and Infrastructure; Responsible Consumption and Production; and Life on Land. This paper aims to provide an overview of each of these technologies, highlighting their applications and addressing concerns farmers may have about adopting these systems on their own operations. Overall, this paper found that automation can be of great benefit to farmers and ranchers who own and operate precision livestock operations of all sizes; however, its applications vary according to personal preferences and necessities. Smaller operations may not reap all the benefits that a larger operation might. For example, many family-run farms do not have the resources to pay for the same high-tech precision technologies that high-producing commercial operations can use on a greater scale. The upfront cost of implementing precision livestock systems can be a limitation for small-scale farmers, and in an era of constant technological advancement, there are additional barriers to keeping them up-to-date. However, with careful consideration and information, farmers can be prepared to improve the efficiency and sustainability of their operations through automation after encountering initial barriers. Through this evaluation, one can better understand how technology is utilized in agricultural production by answering the question: What are the benefits and limitations of precision livestock technologies, specifically automated feeding systems, electronic ear tags, and digital twins with the Internet of Things, and how can they enhance the agricultural industry and create progress toward implementing the United Nations Sustainable Development Goals?

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Introduction

Precision livestock production involves practices such as raising and overseeing farm animals to track their health, productivity, and overall well-being. More specifically, examples include the overseeing of activities such as feeding, breeding, and health management. Precision technologies can aid in these activities. Mechanization leads to the question: How does technology play a role in livestock management and monitoring? Answering this question is important because technology, especially sensors and activity monitors that are most widely used, heavily impacts the efficiency of the agriculture industry. Increased efficiency can yield better quality food and increased welfare, security, and comfort for domesticated livestock, affecting the global food market and consumer perspective regarding farm practices (U.S. Government Accountability Office, 2024). Farmers, although informed about the benefits of such technologies, have held varied and skeptical views on the implementation of precision livestock farming due to factors such as high maintenance costs, a lack of clarity or awareness of technological relevance, and more (Kopler et al., 2023). The three technologies chosen for investigation are automated feeding systems, electronic ear tags, and digital twins through the means of the Internet of Things. Automated feeding systems refer to technologies designed to optimize the livestock feeding process, thereby reducing manual labor for farmers and improving overall precision and efficiency. Ear tags are objects that are attached to an animal's ear and are especially useful for identification, as well as location and disease tracking. Finally, digital twins in agriculture are a virtual representation of a real-world animal or system, using real-time data integration for constant monitoring and easier analysis, simulation, and prediction of the physical entity's performance. These practices will be further analyzed and expanded upon by answering the question: What are the benefits and limitations of precision livestock technologies, specifically automated feeding systems, electronic ear tags, and digital twins with the Internet of Things, and how can they enhance the agricultural industry and create progress toward implementing the United Nations Sustainable Development Goals?

Methods

The methodology for this paper followed a structured process designed to create a comprehensive analysis of the topic. First, relevant United Nations Sustainable Development Goals (UN SDGs) were identified to establish a structure for our research and align it with key sustainability priorities. Next, we searched for credible and peer-reviewed sources by using academic databases and reputable publications. From this step, we gathered fifteen high-quality sources, each of which was then extensively reviewed and further summarized in an annotated bibliography. The information gathered from these sources was compiled to make a detailed introductory section, findings for each of the three technologies and their uses, and the potential direction for future research. Overall, this process ensured that the paper remained evidence-based and aligned with its original sustainability objectives.

Literature Review

Automated Feeding Systems

Automatic feeding systems are perhaps one of the most time-saving technologies for farmers. Before their advent, farmers had to individually measure the amount of feed each animal would receive at mealtimes, usually doing this twice a day. This is a very long and tedious process,

especially for those working on larger operations with several hundred head of livestock. Automatic feeding systems, on the other hand, use data collection and processing to synthesize the nutritional needs of the herd or an individual to suit their mealtime needs best (Pomar & Remus, 2023). By using automation in the feeding process, feeding livestock becomes more time-efficient and precise because it meets the needs of each animal independently (Sonea et al., 2023). This way, farms will be able to run more efficiently and can take care of other needs.

Automatic feeding systems are used for precision feeding and meeting nutrient requirements. Several types of data need to be compiled to find the amount of feed and other supplements required by either an individual animal or a group, including metrics such as water intake, body composition score, and signs of physical and behavioral health (Pomar & Remus, 2023). These data points help agriculturists understand how active their stock is and how to adjust their feed mixtures, accordingly, determining how much and what types of supplements livestock need to receive to maintain their health. Common supplements incorporated into livestock feed include proteins such as soy or cottonseed meal, energy such as corn, and roughage such as hay or corn stalks (Parish & Karisch, 2025). While these foods are supplemental and are not required at the very basic level of a livestock nutritional plan, they may be needed or strongly recommended depending on the purpose of the animal, especially when trying to finish the animal out, during the process of gestation, or when doing heavy work. The data collection process and feeding technology work together to produce a feeding plan and precise execution.

The biggest way that automatic feeding technologies benefit farmers and ranchers is the time management aspect. Depending on the scale of the operation, a farmer can spend several hours a day feeding their livestock. Automated feeding systems can dramatically reduce the time that farmers spend on feeding, and with that extra time, they can work on other more urgent areas of the operation to improve productivity (Romano et al., 2023). Efficiency should be prioritized to maintain productive and sustainable precision livestock operations. Another benefit of a decreased feeding time for the farmer is that more time can be spent with the individual animals. According to Katie Ockert of Michigan State University, spending daily one-on-one time with animals can help catch diseases and other concerns faster (2016). Signs that can indicate illness in livestock are changes in mood, behavior, gait, and eating, to name a few. For example, animals that are not feeling well will often remove themselves or distance themselves from other animals. Being able to identify diseases within a herd or flock is pivotal to protect biosecurity and prevent any further issues, either with the same animal that had been sick or it spreading to other animals on the farm. This way, indications of health issues will be identified and addressed immediately.

There are, however, a few drawbacks and misconceptions related to automated livestock feeding systems. The most notable being the cost for farmers to implement the technology on their operation (Pomar & Remus, 2023). The cost of a feeder averages around \$18,000, which, for many farmers, especially on small family-operated farms, can be highly expensive (Schulte, n.d.). The other large hindrance in using these feeders is that farmers with smaller numbers of animals or with ones that have more specific nutritional needs may not be able to properly implement the technology (Romano et al., 2023). Naturally, with all the animals being fed at the same time, it becomes more difficult to administer individual diets that may have drastically different nutrient and supplement requirements than another animal in the same herd. In general, automated

feeding systems may not be viable in small operations, as a farmer may not be able to reap all the benefits from the technology that a larger operation would.

Overall, automated feeding systems can be beneficial as they create the opportunity for precise nutritional plans for livestock of all species and implement them relatively precisely. Automated feeding systems also have the potential to save farmers and ranchers time by eliminating much of the labor hours needed to feed livestock, allowing for faster disease identification, prevention, and treatment within populations. Improvements that could be made to automatic feeding systems are to make them more practical by reducing costs for smaller farming and ranching operations. Research can also explore the ability to implement individualized nutrition plans for livestock more easily, allowing the system to better cater to each animal rather than the group.

Electronic Ear Tags

Electronic ear tags are devices that have identifiers that store and transmit data. This has benefits for livestock management and helps connect traditional ear tags and precision livestock farming (Kaur et al., 2023). Traditional ear tags are made with the sole purpose of marking livestock for identification, whereas electronic ear tags use microchips to transmit data. Radio-Frequency Identification (RFID) is the most common technology used for this purpose, which helps with proper tracking, security, and data management (Gao et al., 2024).

Within the RFID technologies, there are two different types: low frequency (LF) and ultra-high frequency (UHF) systems. LF tags, commonly used for small groups, are resistant to water and tissue obstruction (Costa et al., 2021). UHF tags, on the other hand, have longer ranges and faster data transfers, and are the most common approach for monitoring animals that move in large herds, as they can quickly scan multiple tags simultaneously (Pretto et al., 2024).

The use of electronic ear tags is crucial for farmers as it helps with disease control, welfare monitoring, and livestock tracking. This technology can help both farmers and veterinarians with tracking animal health using data regarding welfare. In addition, electronic ear tags can also be used with milking systems for dairy cows because they can identify each animal and record its milking information, enabling greater precision tracking for well-being management (Kaur et al., 2023). This will also reduce the demand for labor by preventing the need to collect data manually. The data will benefit livestock monitoring by tracking feeding schedules and vaccinations.

Despite all the benefits of this advancement, electronic ear tags have certain limitations. The largest one remains the cost of implementing the system. This issue is more prominent in smaller farms, which make up 89% of all farms in the nation (United States Department of Agriculture, 2021). Oftentimes, these farmers cannot afford readers, tags, and software for these items. Moreover, errors can occur when using this technology due to incorrect positioning or environmental conditions (Karakus et al., 2015). There is no proper standardized system in place, increasing the chances of complications between different systems. Finally, there are also ethical concerns amongst farmers, like data privacy. This data is highly sensitive as it can change the agricultural market by influencing farmers' decisions and practices (Kopler et al., 2023). Regardless of how substantial this development can be to the industry, it needs to be implemented

with responsibility when handling data, as this would help build trust with farmers, promoting the long-term use of this technology.

As a whole, the positive impacts of electronic ear tags include recording accurate data, improving disease tracking, and increasing efficiency by avoiding manual data tracking. Additionally, ear tags can provide information to help farmers make data-driven decisions, possibly indicating future trends toward automation in the agricultural industry (Ambasht, 2023). Although electronic ear tags are a useful tool for monitoring livestock, there are challenges regarding cost, standardization, and marketing to farmers. Future research can focus on creating a low-cost, standardized system that works for multiple types of farms. It can also explore improved data security to build a trustworthy system. These developments are essential to successfully implementing electronic ear tags by farms in order to transform the agricultural industry.

Digital Twins and the Internet of Things

Digital Twins (DTs) are a concept that links various management and monitoring technologies to build a real-time, online simulation of the entity being monitored. Its applications also extend outside the agriculture industry to serve in other career fields such as weather tracking, engineering, healthcare, and much more (U.S. Government Accountability Office, 2023). In livestock farming, DTs replicate the animals themselves to allow easy, remote viewing for farmers; however, their main purpose exceeds just the simulation.

They function alongside the Internet of Things (IoT), a network of devices that use artificial intelligence to analyze and exchange data within the simulation framework of DTs, referred to as real-time data integration. They work specifically with other precision farming technologies, including physical temperature sensors and cameras. By scanning RFID ear tags, the IoT can identify and access data in each animal's profile, using this data to further control other technologies on the farm. For example, the IoT can collect and analyze data about an animal's eating habits and nutritional needs to update the feeding mixes produced by automated feeder systems (Kaur et al., 2023). By maximizing their technological capabilities in a single, concise online system, they gather the most efficiency from every device. This data is also utilized by DTs to further create adaptive and predictive software in which users can interact with a three-dimensional visualization, which also responds to changes in the scene in real time (Arulmozhi et al., 2024).

DTs have improved the livestock production industry in various ways. The application of precision-based technologies within DTs enhances farmers' ability to cater to each animal on a personal level by improving their ability to monitor the status of each one individually, such as recognizing physical and mental health issues. They are a credible predictor of this information because the program uses the data it receives to analyze current conditions. For example, it can analyze the well-being of animals simply by looking at their facial expressions and ear positions (Neethirajan & Kemp, 2021). DTs can also benefit the agricultural industry by providing information on livestock processing and manufacturing at every stage, optimizing the supply chain and production process (Arulmozhi et al., 2024). Finally, by recognizing signs and indicators through camera sensing, they eliminate the necessity for routine checking and thorough analysis of each animal's well-being. Therefore, the toil felt by large-scale farmers working with many animals or

struggling to recognize problems in their production is reduced, as they can rely on the technology to perform these tasks. With the increased time, farmers are able to better manage their farms, making the work more efficient overall.

That being said, DTs are an ever-adapting and relatively new system, as the idea was only introduced in the early 2000s and did not gain traction until the 2010s. There are numerous problems associated with the technology, the first being its novelty and continuous changes (Arulmozhi et al., 2024). This unreliability dissuades farmers from implementing these technologies, fearful of having to spend more money to keep their systems up-to-date. Also, if the program were to malfunction in these cases, it may potentially cause one to incorrectly predict the status of their livestock and fail to provide proper care. Second, the use of DTs often raises ethical questions, as the digital copy of an organism can be considered an invasion of privacy. However, these concerns do not apply to the agriculture industry because the transmission of information is crucial between manufacturing stages, and the animals are ultimately unaffected by it. Finally, one of the biggest issues associated with using DTs in farming is over-advancement, in which farmers tend to neglect their animals (U.S. Government Accountability Office, 2023). As a result, consumers may argue that DTs view farm animals as data-generated entities instead of sentient beings.

Even though DTs have numerous benefits in automizing livestock management, condensing technological systems, and are a cost-effective and good use of technology, a complete digital twin requires farmers to invest in numerous assisting technologies. This makes it extremely costly to farmers who do not already have technology implemented in their routine, the monetary funds to pursue it, or the education regarding technical usage (Escribà-Gelonch, 2024). State and federal governments can ease these challenges by reducing the costs of implementation to make it more widespread. They can also provide experts to those switching to and learning the system to increase understanding. As digital twins continue to advance and are better introduced to the agricultural market, they will be better integrated into the livestock production industry.

Future Research and Solutions

Future research can analyze the economic changes in farmers' annual income before and after implementing technologies, or it can conduct a comparative study of time and labor efficiency against cost. Alternatively, researchers could survey farmers on their understanding of using such technologies and how they have altered their routine, differentiating between large agribusiness and small-scale farmers. A study of this design may further highlight a lack of comprehension regarding the usage of farm tools. To address these gaps, potential solutions include on-site trainers, a new job title for technological management of growing farmers, and simplifying these technologies to increase accessibility. However, this proposed simplification introduces another challenge discussed in this paper: the difficulty of implementing technology in various-sized industries, especially in smaller farms. As research, design, and development of complex mechanisms continue, it is expected that their usage will improve and costs will decrease. Looking ahead, tailoring technologies to meet individual needs may serve as a future solution.

Conclusion

This paper aimed to address the question: What are the benefits and limitations of precision livestock technologies, specifically automated feeding systems, electronic ear tags, and digital twins, and how can they enhance and sustain the agricultural industry? The research has found that digitizing and automating farming practices have numerous benefits for farming productivity. After overcoming initial resistance, farmers will be equipped to increase efficiency on their farms by effectively understanding the automated technology. For small-scale farmers, ear tags can provide features extending the farmers' capabilities, making them highly valuable. Automated feeding systems may also be used to cater to each animal, but their applications may depend on farm size or farmer preference. Large-scale farms that are already implementing these three technologies will benefit from using digital twins to consolidate their mechanics into a single program, enabling better management of an increased number of animals (Peladarinos et al., 2023). All of these technologies are found to tie directly to the three United Nations Sustainable Development Goals: Industry, Innovation, and Infrastructure; Responsible Consumption and Production; and Life on Land, by creating global redirection toward greater technological access and development, as well as improving the lives of livestock used for food production. Overall, precision farming technologies of various designs can benefit all farmers in multiple ways.

AI Use Statement

AI Tools were used in the original draft to clarify APA 7th Edition citations and to check for grammar and sentence clarity. All applications were checked, reviewed, and further edited in the final paper. Generative AI tools were not used in any part of the research or writing process. All content and analysis reflect the authors' original work.

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