An Evaluation of Smart Livestock Feeding Strategies

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Abstract – The wasteful utilization of feeds is associated with a decrease in profitability. As the demand for feed increases in the future and the competition between food, feed, and fuel intensifies, it is anticipated that there will be significant environmental and social ramifications. The increasing demand for cattle products has given rise to various social, economic, and ecological concerns. This article examines various feeding techniques, encompassing the utilization of smart technology. The implementation of digital technology has facilitated the adoption of a farming technique known as "smart livestock feeding," which ensures the provision of nutritionally balanced food to animals. The result is the production of animals that exhibit improved health conditions and require reduced amounts of both sustenance and medical attention. Farmers can enhance their profits from the trade of leaner and more efficient cattle through the reduction of costs. The significance of this issue arises from the challenges faced by numerous farms worldwide, including factors such as disease outbreaks and insufficient availability of animal feed. The practice of intelligently feeding cattle incorporates advanced technologies such as predictive analytics, big data, and Internet of Things (IoT), information and communication technology (ICT), artificial intelligence, and genomics.

Keywords – Smart Livestock Feeding, Scheduled Feeding, Limit Feeding, Full Feeding, Free Access Feeding, Supplemental Feeding.

I. INTRODUCTION

The implementation of digital technology has facilitated the adoption of a farming technique known as "smart livestock feeding," which ensures the provision of nutritionally balanced food to animals. The result is the production of animals that exhibit improved health conditions and require reduced quantities of both sustenance and medical attention. Farmers have the potential to maximize their profits from the sale of cattle that are leaner and more productive through the strategic reduction of expenses. The significance of this matter lies in the fact that numerous farms worldwide are currently encountering challenges arising from factors such as disease outbreaks and inadequate availability of animal feed. The intelligent feeding of cattle incorporates advanced technologies such as big data, predictive analytics, Internet of Things (IoT), information and communication technology (ICT), artificial intelligence (AI), and genomics.

Animals play a crucial role in global food supply by providing essential sources of sustenance such as eggs, milk, and meat. Moreover, they make a significant contribution to the production of crops via indirect means, including transportation and the provision of fertilizer. Nonetheless, they make a substantial contribution to the well-being of individuals living in poverty in developing countries and play a crucial role in addressing diverse social and economic needs on a global scale. The rearing of livestock also poses various challenges at both regional and international levels. Livestock agriculture is characterized by its high demand for resources, as evidenced by its utilization of approximately 30% of the ice-free land on Earth and 8% of the total global human water consumption. Approximately one-third of all agricultural land is dedicated to the cultivation of feed crops. In addition, it should be noted that the livestock industry plays a significant role in the emission of greenhouse gases (GHGs) caused by human activities, accounting for approximately 14.5 percent of such emissions. This amounts to an annual release of 7.1 Gigatonnes of CO_2-equivalent.

Moreover, it is worth mentioning that the environmental impact of livestock products, in terms of water usage and carbon emissions, tends to be considerably higher compared to plant-based food options. Approximately 45% of the greenhouse gas emissions stemming from the livestock industry can be attributed to the various stages of feed production, processing, and transportation. The emissions resulting from the supply chains associated with pigs and chickens are attributed to feed production at rates of 47% and 57%, respectively. According to Wilfart, Espagnol, Dauguet, Tailleur, Gac, and Garcia-Launay [1], the production of feed contributes to 28%, 36% and 36% of the general emissions linked to buffalo, small ruminants, and cattle, respectively. The aforementioned findings indicate that the methods employed in livestock production necessitate substantial quantities of resources that are currently limited in availability. These resources encompass energy, land, chemicals, and water.

Hence, it is imperative for numerous livestock production systems to adapt and introduce novel approaches in order to meet the future and present demands for animal products in a justifiable way. The implementation of precise feeding practices, which involve the controlled provision of high-quality feed resources to animals through the utilization of advanced engineering and computerized technologies, is widely recognized as essential in industrialized nations and intensive production systems. This approach aims to optimize output by ensuring efficient and disciplined administration of feed resources. The limited availability and inconsistent quality of infrastructure, including unreliable power supply and inadequate maintenance for advanced technological systems, restricts the feasibility of computerized precision feeding to intensive industrialized production systems in select developing nations.

The term "precision feeding" is employed in various contexts within the domain of animal nutrition. However, when applied to farming, it typically denotes the practice of supplying animals with their required daily nutrients in one or multiple portions. The term "balanced feeding" can be considered as a more suitable alternative to "precision feeding" in the context of developing nations, as it encompasses the goal of providing nutrients that fulfill the nutritional requirements of animals throughout the year, while also considering the specific characteristics of the production system. The precision feeding method emphasizes the importance of balanced feeding. However, the balanced feeding approach proposed in this context specifically targets developing country settings. It is characterized by its focus on human-centered, low-tech, and affordable tools and technologies, which are compatible with localized production model and may be supported by present infrastructure. In addition, the utilization of indigenous knowledge pertaining to natural, conserved, and repurposed resources should be maximized in order to attain a state of equilibrium in feeding practices.

The utilization of intelligent feeding systems and techniques has the potential to yield advantages for extended, mixed and mixed extensive crop-livestock production models. This article examines various feeding techniques, encompassing the utilization of smart technology. This article classifies the aforementioned technological advancements into distinct categories. Here is how this paper has been organized: Section II discusses the various methods of feeding livestock. Section III focusses on smart livestock farming technologies, discussing automation and application of biometric sensors, and IoT and CPS. Section IV reviews information and communication technologies such as machine learning and data analytics, cloud computing, and genomics. Lastly, Section V draws final remarks to the paper.

II. DIFFERENT METHODS OF FEEDING LIVESTOCK

The selection of an optimal feeding method for livestock can significantly impact the overall well-being and productivity of the animals, as well as the sustainable viability of the agricultural operation. Animal owners have a range of feeding alternatives available to them, which encompass scheduled feeding, limit feeding, full feeding, free access feeding, and supplemental feeding.

Scheduled Feeding

In this type, a feeding platform will be supplied with hay, grain, or vitamins at predetermined intervals. By employing this approach, one can effectively ensure the timely provision of care for their animals. The concept of "scheduled feeding" pertains to the practice of providing animals with regular meals at consistent time intervals throughout the day. It is possible to have one, two, or even three feedings per day. The objective of implementing a feeding schedule is to establish a conditioned response in animals, prompting them to gather at the designated feeding location during the designated feeding times. This practice guarantees that all animals within a large enclosure are provided with an equitable opportunity to consume an equivalent amount of sustenance. A significant number of individuals rear their canines with the anticipation of receiving consistent meals at specific intervals.

Individuals who are occupied with extensive work commitments and are only able to attend to their canine companions in the early mornings and evenings tend to adhere to a predetermined feeding regimen for their dogs. The optimal functioning of a dog's digestive system is facilitated by the availability of external waste excretion, which concurrently aids in the process of house training. During the calving season, certain cattle farmers employ a scheduled feeding approach for their gravid cows. There is an increased likelihood of cows in close proximity to calving giving birth during daylight hours when they are provided with late evening feeding. While this strategy is not infallible, it effectively consolidates deliveries within a condensed timeframe, thereby increasing the likelihood of obtaining assistance from a larger pool of individuals, if necessary.

Limit Feeding

This technique, known as total mixed ration feeding, involves supplying cattle with a complete and balanced diet for a specified duration. It is imperative to meticulously quantify the quantity of food provided to them. Animals subjected to limit-feeding practices receive a quantity of food that is sufficient to meet their basic nutritional needs. The implementation of a limit-feeding diet does not result in either weight loss or growth in animals. The objective of this approach is to maintain the well-being of animals while ensuring that their physiological processes remain unaffected. Both adult pets and zoo animals should be subjected to calorie-restricted diets. The provision of excess feed leads to the accumulation of adipose tissue due to the maintenance of a consistent daily energy intake. Animal caregivers should exercise caution when implementing limit feeding strategies during periods of inclement weather. The expenses associated with maintaining suitable thermal conditions for animals will be higher when they are accommodated in outdoor facilities. If this process persists, both fat and muscle, which are essential components, will undergo metabolism. A modest increment suffices for animals that are kept indoors or within a sheltered environment.

Full Feeding

Consuming an amount of food that sustains one's current body weight is a widely accepted guideline for maintaining a balanced diet. It is an effective method for achieving cost savings without compromising on quality. Animals that maintain a consistent energy expenditure and reside within a limited habitat derive advantages from being provided with a sufficient amount of food. In the context of animal feeding, the practice of providing animals with an ample quantity of food within one or two meals is commonly referred to as full-feeding. The process of manually transporting and distributing feed to animals is commonly known as hand feeding. Animals in the final stages of their growth cycle, nearing their optimal weight for harvest, are typically provided with a diet that meets their full nutritional requirements. Animals that are provided with a comprehensive diet experience accelerated weight gain, resulting in the production of carcasses that exhibit superior quality. The practice of full-feeding typically involves the utilization of a feed that has a high concentration, along with the addition of various nutrients such as vitamins and minerals. The gradual introduction of full feeding is recommended for animals. It is recommended that feed be promptly removed within a few hours after being administered, and the quantity of feed provided should be gradually increased over an extended period of several weeks.

Free Access Feeding

This practice, commonly referred to as "free-choice feeding," grants animals the autonomy to forage on a wide range of resources within an expansive territory. In geographical areas characterized by diurnal temperature variations, wherein the daytime temperatures are high while the nighttime temperatures are comparatively lower, the implementation of free access feeding has the potential to yield advantageous outcomes. The animals have the tendency to seek refuge from the sun throughout the entirety of the day, opting to graze during the night when temperatures are more tolerable. It is imperative that animals are afforded unrestricted access to feed at all times. The practice in question is commonly referred to as free-choice feeding. The animals are provided with ample access to feed, enabling them to freely consume it at their convenience through regular visits to the designated feeding facility.

In geographical areas characterized by high daytime temperatures and low nighttime temperatures, this approach can prove to be highly beneficial. Throughout the daytime, the animals would actively seek refuge in regions characterized by lower temperatures, while reserving their feeding activities for the nocturnal hours. Free-access feeding is a commonly employed practice for a diverse range of animals, encompassing market pigs as well as domesticated pets. This method is considered ideal for market pigs, as it does not pose any harmful effects associated with overfeeding. Nevertheless, canines that have unrestricted access to sustenance are prone to excessive consumption and subsequent weight gain in the absence of regular physical activity. This may lead to physical harm and the development of chronic health conditions.

Supplemental Feeding

Supplemental feeding entails the provision of additional nourishment to animals that primarily subsist on grazing. This method enables cattle, lambs, and other livestock to acquire the necessary nutrients for their optimal growth and development. Supplemental feeding may provide benefits to animals whose primary diet is centered around hunting or grazing. Supplementary feeding is a commonly employed method in the husbandry of domesticated animals such as sheep, cattle, and goats, as well as in the management of captive wild animals. The supplementary feeding strategy has the potential to enhance various nutrients, including protein, energy, vitamins, and minerals. In regions characterized by hot, arid summers and cold, snowy winters, grazing animals may encounter challenges in obtaining sufficient sustenance. The following periods are characterized by the frequent utilization of supplementary feeding. Some farmers employ a technique known as flexible mental feeding to train their animals. Animals can be subjected to capture or confinement for the purpose of experimentation, provided that they are lured through the provision of sustenance.

III. SMART LIVESTOCK FARMING TECHNOLOGIES

The demand for cattle products has experienced a significant increase due to the rapid growth of the population in recent years. Nevertheless, due to the phenomenon of climate change and the limited availability of cultivable land, meeting these demands has proven to be challenging. Animal agriculture is responsible for the utilization of approximately one-third of the global freshwater resources and up to 80 percent of the world's arable land. The integration of smart farming technology into agriculture is imperative to address the challenges associated with livestock production and ensure a consistent provision of animal products. Below, a selection of these structures is provided.

Automation and Application of Biometric Sensors

Automation is a highly effective tool in the maintenance of a healthy and contented herd. By vigilantly monitoring the welfare and conduct of your animals, you will be able to allocate additional time to attend to other crucial tasks. The implementation of automation in tasks such as animal breeding, feeding, and transportation results in significant time and labor savings. The utilization of computers and other electronic devices holds significant importance in the context of precision livestock farming (PLF) [2]. The objective is to mitigate the impact on the environment while simultaneously enhancing productivity and reproduction, as well as promoting the well-being of both humans and animals, and optimizing resource utilization efficiency. The utilization of digital technology for the purpose of documenting various parameters pertaining to individuals, groups, and environments serves as the fundamental basis of PL.

The integration of technology into the agricultural sector has facilitated the streamlining of repetitive tasks. An illustration of technological advancement can be observed in the shift from manual milking to mechanized milking, a transformation that has taken place over the past century and a half. During the 1980s, notable progress in this particular domain resulted in the emergence of automated milking systems, commonly referred to as milking robots. These technological innovations offered numerous advantages to farmers, such as enhanced labor productivity and the automated collection of various animal-related data points.

According to Satyanarayan, Jagadeeswary, Belakeri, Babu, and Srinivas [3], the integration of digital technology within the livestock farming system has the potential to offer novel solutions to challenges arising from increased animal densities and the demand for environmentally sustainable and animal-friendly production practices that minimize resource consumption. The overall observation, however, indicates significant variation in the rate of adoption of digital technology across specific technologies, animal species, and academic disciplines. Hopson [4] has provided examples of digital technology that have been employed in the milking industry for a considerable period of time, such as milk quantity sensors and automated concentrate feeders. Karcher and Mench [5] assert that commercial poultry operations commonly employ egg counting, bird weighing, and technologies related to environmental and feeding management. Nevertheless, certain technologies have existed for a considerable period of time; however, their adoption in the domain of cattle production remains limited. Milking robots represent a specific type of automated milking system, as discussed by Fedorenko et al. [6]. Additional examples encompass animal tracking systems and automated heat detection mechanisms.

While the majority of existing studies have primarily examined crop farms, the literature suggests a relationship between socio-demographic factors and the adoption of technology. Additionally, certain types of farms or firms exhibit a higher propensity for utilizing modern technologies compared to others. Several factors, such as farm size, production method (organic or conventional), farm specialization, and farmer age, have been identified as potential influences on a farmer's inclination to adopt new technology. The results vary based on the technological methods employed as well as the geographical context of the research. In a study conducted by Yurtman et al. [7], it was determined that there was no significant correlation observed between the age of commercial sheep farmers or the size of their farms and their utilization of electronic identification tools.

However, in a separate investigation conducted by Konrad, Nielsen, Pedersen, and Elofsson [8] focusing on the adoption of nutrient abatement technologies, contrasting results were obtained. Specifically, it was found that the adoption of such technologies increased in proportion to the size of the farm, but conversely decreased among farmers aged 65 and older. The adoption rates of milking robots exhibit significant variation among different nations, as outlined in the comprehensive summary provided in [9]. In Denmark and Sweden, the adoption of milking robots in dairies exceeds 20%, whereas in other countries such as Iceland and the Netherlands, the utilization rate ranges between 10% and 15%. Similarly, Norway, Finland, Germany, and Canada exhibit a 10% usage rate of milking robots in their respective dairy industries. Nevertheless, the research employed a wide range of sampling methods, some of which were not necessarily representative.

In contrast, husbandry systems exhibit a lower degree of adaptability and are characterized by long-term planning spanning several decades. This distinction plays a pivotal role in the differential adoption of digital technology between the livestock industry and plant production. The significant initial investment and the subsequent requirement for ongoing maintenance may potentially serve as a contributing factor. In the context of Switzerland, it has been reported that the period required to recoup the investment made in a newly constructed dairy cattle barn is estimated to be 25 years. The initial capital outlay for such a facility varies between 11,000 and 22,000 Swiss francs per cow spot. The utilization of digital technology may also be influenced by the type of husbandry. One approach involves utilizing activity sensors to monitor the behavior of each individual animal. Due to the limited ability of cows in tie stall barns to exhibit natural behaviors, the data obtained from them may not provide an accurate representation of the animals' welfare, as compared to the data collected from cows in loose housing systems.

Switzerland's agricultural sector benefits significantly from its favorable topography and climate, leading to the prominence of livestock production within the country. According to the data provided by the Federal Statistical Office (FSO) in 2017, the majority of farms, specifically 74%, were primarily engaged in livestock production [10]. Additionally, it was observed that 70% of the total agricultural land was allocated for the cultivation of fodder crops. According to Stanton, Heady, Johnson, and Hardin [11], the average farm size in 2018 was approximately 20.5 hectares. This figure indicates that the average farm size is comparatively small when compared to neighboring countries such as Germany or France. Financial assistance for sustainable agriculture is provided by the Swiss federal government, thereby facilitating the preservation of smaller-scale and more diverse farming operations. Nevertheless, Switzerland is aligning itself with the prevailing global inclination towards larger specialized agricultural establishments, resulting in a reduction in the overall quantity of farms within the country, accompanied by an increase in their average size.

The data indicates a significant increase of over 50% in the count of farms encompassing 50 hectares or greater in land area from 1975 to 2018 [12]. Furthermore, it has been observed that there has been an increase in the overall number of animals present on farms. The legislation enacted by the Swiss Federal Council pertaining to the upper limit on livestock in meat and egg production establishes legally prescribed thresholds that impose constraints on the quantity of animals permitted per agricultural establishment. In Switzerland, tie stall barns and loose housing systems are both utilized, although the prevalence of the latter is diminishing. The prevailing practice for housing suckler cows, beef cattle, goats, and sheep is to provide them with loose housing.

Farmers have the ability to assess the well-being and health of cattle over a period of time by utilizing data obtained from biometric sensors. The assortment of biometric sensors currently available in the market can be categorized into two main types: non-invasive and invasive. Non-intrusive sensors, such as sensors and surveillance cameras incorporated into the feeding models, can be strategically positioned throughout the barn to collect and monitor data pertaining to food intake and animal weight. The non-invasive sensors capable of detecting animal behavior without causing harm include pedometers, microelectromechanical system (MEMS) and global positioning system trackers based activity sensors. In the realm of bovine research, there has been relatively limited investigation into invasive sensors, which are typically introduced into the animal's body either through ingestion or implantation. This class of sensors can be utilized to monitor internalized physiological markers like vaginal pressure, body temperature, and rumen health in dairy cows.

The livestock sector has implemented biometric sensor technology in order to obtain precise and unbiased evaluations of animal health and welfare, as well as to monitor a larger number of animals without requiring additional contact time or personnel. Algorithms, defined as ordered sets of instructions or computations employed for problem-solving purposes, are utilized in the processing of data acquired from sensors and subsequently stored in databases. Specialized algorithms are employed to analyze the unprocessed data collected by biometric sensors attached to livestock. These algorithms provide valuable physiological insights, such as the duration of specific activities undertaken by animals within a day or the fluctuations in their activity levels over defined time intervals. In addition, these sensors can be configured to identify atypical behavior that falls outside a predefined range, thereby notifying agricultural practitioners. This enables them to promptly inspect the animal and implement appropriate measures to safeguard its ongoing physical condition and overall welfare. The facilitation of animal identification and selection for breeding programs can be enhanced through the integration of biometric sensors with bioinformatics technologies, big data analytics, and artificial intelligence, similar to those employed in genomics.

According to projections, the utilization of biometric sensors is expected to increase in the animal health sector, specifically in the domain of cattle farming, over the course of the next decade. This is due to the fact that they offer numerous advantages, such as significant levels of instantaneous output, precise accuracy, and availability of extensive amounts of data. The feasibility of early intervention is attributed to the accessibility of information, and the prompt acquisition of such information often diminishes the necessity for subsequent interpolations. Thermal infrared imaging (TIR) may be employed as a viable alternative to conventional invasive thermometers, which necessitate the handling and confinement of animals in order to measure their body temperatures. The utilization of thermal infrared imaging (TIR) as a means of stress monitoring and disease diagnosis has been found to provide earlier detection, approximately 4-6 days in advance compared to conventional methods. This expedited identification enables prompt treatment and mitigates the risk of disease transmission within flocks or herds.

Accelerometers, thermometers, radio-frequency identification (RFID) tags, cameras, and microphones are commonly employed non-invasive sensors in the field of livestock animal monitoring. These technologies allow farmers to monitor various aspects such as barn acoustics (e.g., sneezing and coughing), aggression levels in pigs, weather conditions, and the activity levels of the animals. To ensure consistent excellence in the final product, it is possible to evaluate the quality of meat by comparing it to stress measurements obtained from various physiological sensors like thermometers, heart rate monitors, and TIR (thermal infrared) sensors. Scientists have the capability to observe real-time fluctuations in heart rate in reaction to both negative stressors and positive stressors (eustress). This is made possible through the utilization of biometric sensors.

Furthermore, scientists are able to conduct comparative analyses of these reactions across different animal species as well as over different time periods. A study conducted by Byrd, Johnson, Radcliffe, Craig, Eicher, and Lay Jr [13] revealed that pigs exhibited sustained elevation in heart rate subsequent to exposure to a loud auditory stimulus, indicating a persistent physiological response to the aversive stressor. The heart rate remained elevated for a duration of two minutes subsequent to the encounter with a positive stressor, namely, the interaction with a towel for recreational purposes. Traditional or indirect measures of well-being may not capture these subtle nuances. Heart rate monitors have the potential to be beneficial in the domains of health and metabolic energy production. The continuous monitoring of cattle heart rates can be achieved by utilizing biometric sensors like photoplethysmographic sensors, in integration with ear tags, including other parts of the body.

There is an increasing trend among farmers to employ radio frequency identification (RFID) devices for the purpose of monitoring the location and behavior of their livestock. These devices have the potential to be affixed to the auditory organs of the animals, their neck accessories, or inserted subcutaneously. Microphones and acoustic analysis enable farmers to monitor vocalizations and coughing sounds, thereby offering timely detection of welfare issues. According to a study conducted by Salman, King, Odde, and Mortimer [14], it is possible to efficiently and inconspicuously install microphones within barns for the purpose of monitoring animal herds. In a similar vein, the expedient and effective installation of cameras in barns facilitates the capture of a diverse array of valuable data. Video image algorithms can be utilized to detect signs of lameness and other health issues in animals. Cameras have the potential to be utilized for monitoring various aspects of animals, including their body mass index, water consumption, behavior, and aggressiveness.

Automated animal welfare monitoring has garnered considerable attention due to the utilization of facial recognition technologies. Facial detection techniques depend on the algorithms of machine learning to effectively detect characteristics on the animal faces for the purpose of identification or monitoring changes associated with emotional states. Mogil, Pang, Silva Dutra, and Chambers [15] concentrated on animal welfare are currently engaged in the development of "grimace scales" specifically designed for livestock. The primary objective of these scales is to assist farmers in effectively identifying signs of discomfort exhibited by animals. Livestock animals undergo different processes, such as castration, tail docking, and dehorning, which are commonly practiced. The intentions of animals can be discerned through the meticulous analysis of their facial expressions during various behaviors. Previous studies have demonstrated that there exists a discernible distinction in facial morphology between pigs exhibiting aggressive behavior and those that do not. Furthermore, as a cost-effective alternative for individual animal identification, facial detection has been proposed alongside RFID tags.

Biometric sensors play a fundamental role in mitigating the severity and transmission of illnesses. The monitoring of various parameters such as temperature, sound, behavior, and physiological indicators like metabolic activity, pH, infections, and the availability of antibiotics or poisons can be facilitated through the utilization of appropriate sensors. There exists substantial evidence indicating that the improper use of antibiotics in the context of cattle agriculture has adverse effects on human health. The ability of farmers to effectively treat sick animals and guarantee the global availability of safe and nutritious animal products has been enhanced through the implementation of antibiotic tracking methods. Furthermore, biosensing technology has the potential to be utilized for the identification of Johne's disease, a damaging bacterial infection predominant in ruminants, which can lead to substantial financial burdens for agricultural practitioners. Furthermore, the identification of indicators of inflammation can be accomplished through the utilization of biometric sensors, which can provide a comprehensive means of monitoring various diseases. For example, thermal infrared imaging (TIR) has been employed to capture images of feet for the purpose of diagnosing foot ailments.

Internet of Things and Cyber-Physical Systems

The rapid integration of intelligent devices has been observed in various sectors, encompassing the agricultural industry. There has been an increase in the adoption of Internet of Things (IoT)-enabled sensors within the agricultural sector. These devices are utilized for the purpose of monitoring animals and transmitting the collected data to servers located remotely. The utilization of the CPS and IoT framework can provide supplementary understanding of one's agricultural enterprise and its operational processes. In the context of precision agriculture, this technology finds utility in diverse applications such as soil mapping and the monitoring of animal health. The scalability volume and processing capability of the current architectural frameworks have been attained through the augmentation of linked IoT appliances. Therefore, it is imperative to identify a methodology that is capable of accommodating dynamic situations.

The cloud-based Internet of Things (CB-IoT) [16] is increasingly being recognized and embraced as a feasible and advantageous alternative. Cloud computing offers a wide range of data processing and storage possibilities by means of its virtualization architecture. This implies that multiple central processing units (CPUs) within the cloud data center have the capability to concurrently process individual applications. The Cloud's capacity to enhance the performance of IoT devices with limited power, computational capabilities, and storage capacities offers a potential solution to the constraints faced by such devices in these domains. The utilization of AWS Cloud IoT services is recommended for the purpose of reconfiguring and ensuring the scalability of the architectural framework of pre-established enterprises. Cloud computing is considered to be a more cost-effective and reliable alternative to the traditional computer strategy, which heavily relies on an in-house server farm. Cloud computing has led to a paradigm shift in IT spending, with the adoption of a pay-as-you-go model becoming increasingly prevalent.

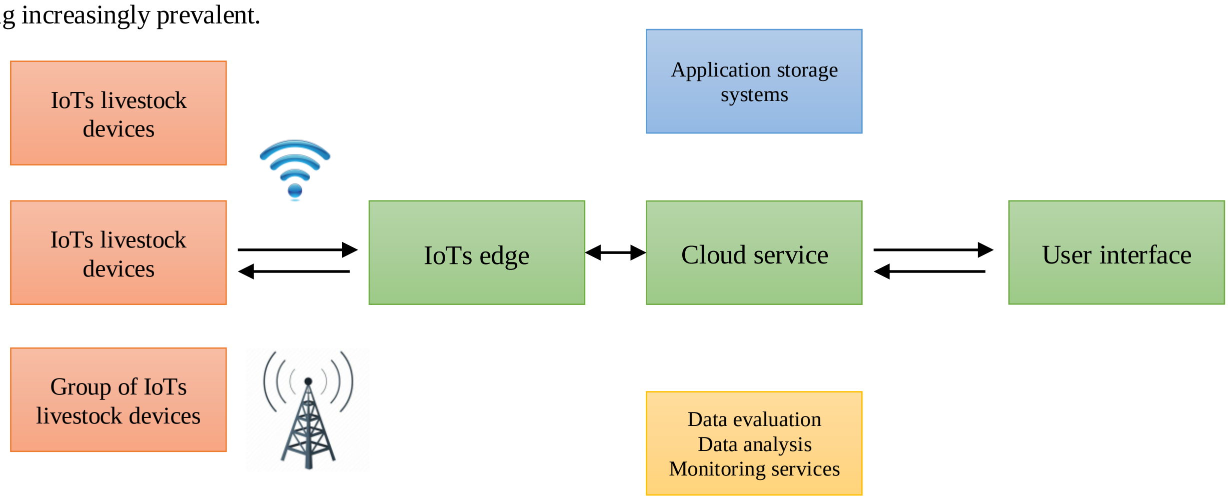

Fig 1. An architecture that has been constructed based on the utilization of Amazon Web Services

The system in **Fig 1** utilizes a diverse range of cloud services and cyber-physical systems/internet of things (CPS/IoT) devices. Ning and Jiang [17] discloses valuable insights regarding the utilization of Cyber-Physical Systems (CPS) and Internet of Things (IoT) data. The utilization and analysis of structured and unstructured data to derive valuable insights enhances the data's overall worth. The limited usability of commercially available monitoring tools is attributed to the absence of well-defined protocols for sensor data exchange. The main aim of this study is to develop methodologies for transforming data into applicable solutions. Handling data from Cyber-Physical Systems (CPS) and Internet of Things (IoT) devices poses significant challenges due to various factors. The presence of significant background noise in the data can be attributed to the occurrence of capture and transmission errors. The unpredictability of the data arises from its diverse sources and the potential application of various temporal representations. The value of the data is greatly influenced by the consistency of data collection and the precision of data analysis.

Despite the shared origin of the data from identical devices, it is crucial to bear in mind that they may exhibit unforeseen responses, even when subjected to identical testing protocols. One of the fundamental aspects of data processing involves the conversion of unstructured data streams into structured ones, as well as the extraction of meaningful information from irrelevant or noisy data. The inherent variability and lack of precision in the data obtained from IoT devices presents an additional layer of intricacy in the endeavor to derive meaningful insights and extract business value from it. The data obtained from diverse intricate sensors is typically in an unprocessed and frequently imbalanced state, thereby requiring obligatory pre-processing. One essential aspect in the utilization of machine learning algorithms for the purpose of detecting concealed relationships within data sets, which can subsequently be employed in the development of predictive and categorization models, is the imperative process of arranging, purifying, and verifying the data.

One potential approach for achieving effective animal husbandry monitoring is through the implementation of a CPS/IoT system that maintains a continuous connection to a cloud-based control unit. The objective of the system is to gather data from a multitude of Internet of Things (IoT) devices at predetermined intervals or in immediate succession. The process involves the collection, consolidation, analysis, and retention of data in adherence to system specifications and the prevailing operational framework, prior to transmission through multiple channels to a distant server. This system enables the monitoring and documentation of indicators pertaining to health and behavior. The system's flexible device models enable the availability of numerous configurations of sensors and communication modules. The selected devices and sensors concerning Internet of Things (IoT) will undergo rigorous assessments to evaluate their precision and dependability. It is anticipated that the system will be compatible with IoT sensor modules that possess limited hardware capabilities. As a result of this, the system has the potential for enhanced performance in contrast to prior systems that have been hindered in their ability to advance due to limitations in hardware or software. The platform's ability to communicate with distant devices and the cloud using WiFi, ZigBee, LoRaWAN, or Z-Wave demonstrates its versatility and lack of dependence on any specific platform.

IV. INFORMATION AND COMMUNICATION TECHNOLOGIES

The utilization of mobile phones, wireless networks, and the internet for livestock monitoring is increasingly prevalent. The ability to scan a numerical code on a cow's ear tag or utilize a smartphone application to assess the well-being of one's livestock is now accessible from a wide range of locations.

Machine Learning & Data Analytics

The utilization of analytics applied to agricultural data has become increasingly prevalent among farmers, as it enables them to make more informed decisions and enhance their output [23]. The process of collecting, storing, and analyzing data can provide valuable insights for making critical agricultural decisions, such as determining the optimal course of action regarding the acquisition or sale of livestock, the allocation of limited water resources, and the appropriate quantity of feed to be stockpiled. Machine learning has the potential to facilitate the acquisition of knowledge from data and generate predictions, thereby enhancing productivity and efficiency [24].

Automated systems demonstrate exceptional proficiency in the domains of rapid data collection, processing, and analysis. The ability to make sound decisions is hindered in the absence of relevant information [25]. By engaging in the collection and examination of extensive quantities of intricate data, individuals have the potential to assist others in making more informed decisions [26]. Real-time animal behavior monitoring facilitated by a range of sensors can potentially offer advantages to farmers [27]. The integration of big data and advanced algorithms can be employed to observe, quantify, and comprehend alterations in animal behavior. Consequently, farmers are able to make more informed decisions and promptly address diseases [28].

There is currently a wide range of sensors available in the market that enable farmers to effectively monitor various aspects such as animal activity, dietary patterns, sleep patterns, and even air quality within kennels [29]. A computer system that is capable of handling substantial volumes of data is responsible for both storing and processing the unprocessed data. In conclusion, machine learning algorithms prioritize the detection and analysis of any deviations or anomalies from the established patterns or standards.

The early detection of various illnesses in pigs and sheep can be achieved through the utilization of sensors, big data, and machine learning algorithms, which enable the monitoring of the animals' body motions, reaction times, and overall activity levels. Farmers may encounter difficulties in perceiving these alterations within a large assemblage of livestock due to the substantial number of animals present.

Identifying a sick animal within a large herd poses an additional level of difficulty for farmers or caregivers, as it necessitates the observation of alterations in dietary patterns, hydration levels, or abnormal bodily movements. Farmers can potentially derive significant advantages from being informed about atypical behaviors through the utilization of sensors, big data, and machine learning techniques. This knowledge can subsequently enable them to promptly identify and prevent disease outbreaks.

As an illustration, within the poultry industry, the utilization of air sensors has enabled the early detection of Coccidiosis, a highly contagious gastrointestinal disease in birds that frequently exhibits no visible symptoms during its initial phases. Continuous monitoring of air quality is one method employed to identify the presence of this ailment. As the number of avian specimens exposed to the virus increases, the concentration of volatile organic compounds (VOCs) in the atmosphere intensifies. Air sensors can detect this shift before it becomes apparent to farmers or doctors. When farmers receive a warning, they are likely to respond promptly in order to mitigate the spread of the disease. This method contributes to the preservation of numerous animal lives and prevents the unnecessary expenditure of financial resources.

In a similar vein, the utilization of sensors, extensive data, and advanced algorithms has demonstrated superior predictive capabilities in forecasting specific illnesses in large animals, surpassing the abilities of human observers. Cattle afflicted with udder ailments such as mastitis exhibit reduced milk production on the basis of both quantity and quality. The manual determination of somatic cell counts (SCC) and electric conductivity (EC) values has been conventionally employed for the identification of mastitis. Manual readings possess inherent limitations and may not consistently exhibit accuracy or utility. Automated sensors and algorithms have been shown to be effective in the collection, prediction, and mitigation of mastitis occurrences in cows.

The novelty of methods for early illness detection is limited. There are already existing technologies, such as RtPCR, that can accomplish this task. Regrettably, the exorbitant cost and restricted scope of application hindered the widespread adoption. The conventional methods of detection mentioned in the text incur higher costs compared to the contemporary alternatives such as sensors, big data, and machine learning algorithms (see **Fig 2**). The ability to promptly predict and mitigate the occurrence of infectious diseases, such as African Swine Flu, can be achieved at a significantly reduced expense. The anticipation of the spread of numerous infectious diseases has been made possible by advancements in modern technologies (see **Table 1**).

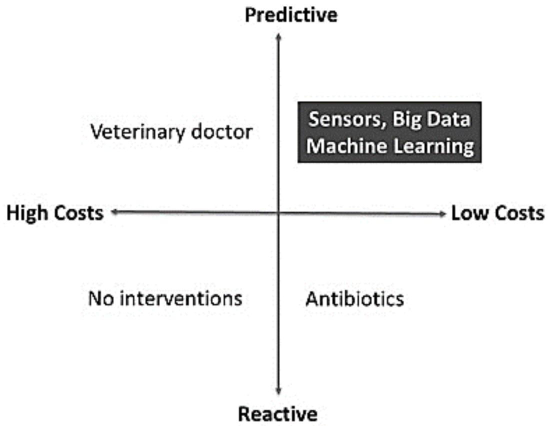

Fig 2. Contrast between the Proactive and Reactive Approaches to Animal Illness Management

Table 1. The role that cutting-edge technology plays in assisting farmers with illness forecasting and disease prevention in their animal populations

Illness	Algorithms	Determined Parameter
African swine flue	Gradient boosted trees, bag of words	Optical flow approach
Coccidiosis	Regression tree XGBoost, fog computing and classification	Air volatile organic compound
Postpartum disease	Random forest	Milk yield, protein production, lactose yield
Lameness	Principal component analysis	Video/image data, neck movement, and leg movement
Mastitis	Optical flow approach	Mobility, direction, speed

Algorithms can also be employed for the purpose of identifying lameness and other indications of illness in animals. The presence of preclinical lameness is consistently identified through observable changes in movement patterns, increased utilization of specific body regions, and decreased activity in other areas. Lameness, as supported by Nalon and Stevenson [18], ranks as the third most significant ailment impacting the agricultural sector. This condition is known to result in a substantial reduction in milk production and an elevated susceptibility to injuries. By proactively identifying and predicting lameness in livestock, farmers have the potential to mitigate economic losses.

Alarcón, Allepuz, and Mateu [19] indicate that infected pigs exhibit a notable reduction in their level of activity, reaching up to a 10% decline within the initial two days following infection. This practice establishes a fundamental basis for the segregation of afflicted animals, thereby preventing the transmission of their infection to other animals. Sensors capable of capturing ambient conditions, such as temperature, gas emissions, and humidity, have the potential to assist farmers in mitigating bacterial infections and gastrointestinal ailments in pigs. The presented case studies provide examples of how the utilization of sensors, big data, and machine learning techniques can potentially assist farmers in promptly identifying and mitigating various diseases, without incurring any costs or disruptions to crop production.

Cloud Computing

There have been two previous agricultural revolutions. The initial phase of agricultural modernization involved the implementation of mechanization, which was subsequently followed by the introduction of genetic modifications during the period commonly referred to as the "green revolution". Agriculture 3.0, alternatively referred to as Precision Agriculture, is a paradigm shift that has been in progress since the latter part of the 1990s. It is distinguished by the extensive adoption of advanced initiatives such as Global Positioning Systems (GPS), Geographical Information Systems (GIS), and sensors. They facilitated the expeditious application of deep learning and machine learning techniques in the domain of computer vision, along with various other domains pertaining to image processing.

The latter serves the purpose of differentiating between undesirable plants and cultivated crops, as well as facilitating the identification of specific crops and the detection of diseases, among other applications. The emergence of Agriculture 3.0 has generated a substantial volume of data, thereby prompting the development of big data tools to facilitate its analysis. This development signifies notable transformations across various academic fields. Klappe, Cornet, Dongelmans, and de Keizer [20] assert that the identification of patterns, curation of mistakes, elimination of duplicate or inconsistent data, and resolution of noise issues can be achieved through the systematic recording of collected data.

Utilizing autonomous context awareness providers, the concept of "smart farming," alternatively referred to as "smart agriculture" or "agriculture 4.0," presents innovative approaches to enhance the adaptability, effectiveness, and resilience of agricultural production systems. Moreover, it aims to bolster competitiveness and profitability, ensure equitable resource allocation, and mitigate food wastage. Smart Farming encompasses a broad range of topics that extend beyond the boundaries of the farm, including farmer decision-making, biodiversity, supply-chain management, food availability and quality, insurance, and environmental/earth-sciences research.

The distinguishing characteristic of Smart Farming, in contrast to other Internet of Things (IoT) applications, lies in its emphasis on the integration and management of living organisms, specifically plants and animals. Privacy concerns are not prevalent in the domain of medical Internet of Things (IoT); however, apprehensions regarding the confidentiality of data arise within the manufacturing process. The utilization of hierarchical routing in Wireless Sensing and Actuating Networks (WSANs), which employ Low-power and Lossy Network (LLN) technology, enables the collection of data and the activation of devices. This approach is commonly observed in various Internet of Things (IoT) applications. Multi-path routing protocols can be employed to distribute the data transmission load and manage energy consumption in nodes that have limited battery life, basic computing capabilities, a distinct communication identification, and/or restricted resources.

The limited duration of battery usage presents challenges in terms of device recharging or replacement, potentially rendering these actions difficult or unfeasible. In addition to managing the active and inactive operational periods and scheduling the transfer of information, it is imperative to incorporate energy-saving and ambient energy strategies. Additional elements that can be incorporated include tablets utilized for encoding precise observations, publicly accessible geospatial services, as well as external resources such as interconnected agricultural vehicles, automated milking robots, unmanned ground vehicles (UGVs), unmanned aerial vehicles (UAVs), mobile devices, and similar technologies.

In regions such as India, small-scale family farms have adopted Internet of Things (IoT) technology by utilizing a limited number of affordable sensors and actuators. Conversely, large-scale farms in the American Midwest employ a significantly higher quantity of commercial sensors, numbering in the tens of thousands, alongside hundreds of interconnected machines that are connected to the internet. The heterogeneity of objects in smart farming is a notable characteristic, wherein each object has the ability to generate data at varying rates, ranging from a few bytes per second to gigabytes per second. Furthermore, the choice of architectural design is influenced by the availability and effectiveness of network protocols in rural areas for transmitting this data. Applications necessitate the use of real-time and/or asynchronous treatments.

The demand for instantaneous responses varies significantly across different applications. The operation of drone remote control requires a prompt response time of a few milliseconds. Similarly, applications such as Variable Rate Fertilizer (VRF) and Variable Spraying (VS), which aim to optimize the effectiveness of nutrient and herbicide application, also require response times ranging from a few milliseconds to a few seconds. The real-time processing of a herd of cattle can vary in duration, ranging from a few minutes to several hours. The duration for which data is retained exhibits significant variability across different use cases. Unmanned aerial vehicles (UAVs), for example, produce substantial quantities of photographs that necessitate immediate transmission to the cloud for prompt analysis or storage. The specimens can be subjected to additional processing within a batch processing environment in order to extract additional information. The photographs obtained through the utilization of Unmanned Ground Vehicles (UGVs) become obsolete subsequent to their processing and application within a given mission. Nevertheless, data possessing distinctive, innovative, or exceptional attributes could be preserved for subsequent utilization, potentially augmenting artificial intelligence systems. Certain sensors exclusively generate data upon detecting an anomaly, whereas others transmit minimal quantities of data at consistent intervals.

Cloud computing utilizes a distributed network system in order to store, manage, and analyze data. Farmers have the option to conveniently and economically store their paperwork in this location, rather than allowing it to accumulate in their residences. The acronym "Smart" is often used to describe a range of advanced computing, sensing and communication systems and techniques. The integrate different cloud-oriented and Internet applications and connection modalities, as well as the integration of different paradigms. The term "smart" encompasses a range of interpretations, but it commonly denotes a configuration wherein physical apparatuses are interconnected with computer systems to facilitate the gathering, manipulation, transmission, and examination of data. The fundamental components of smart computing and sensing in contemporary times encompass networked wireless and wireline sensors, wearable computing devices, next-generation cellular networks, sensing systems and energy-efficient computing and big-data visualization, and processing.

Smart technologies are generating significant social and economic benefits, with the potential to persist in various unconventional sectors. The advancement of intelligent computers and technology holds great potential for enhancing various domains, including animal welfare. The term "animal welfare" is employed in a comprehensive manner, encompassing considerations such as the provision of fundamental necessities, the maintenance of good health, the absence of pain and suffering, and the promotion of positive stimulation within an animal's environment. Consider the livestock industry as an illustrative example. While there is currently no universally recognized United Nations declaration specifically addressing the involvement of animals in sustainable development or providing guidelines for accountable investment in agriculture, it is apparent that animals play a vital role in promoting the long-term sustainability of these industries and safeguarding the well-being of both humans and the environment.

There is minimal doubt that the technology currently being heavily invested in for agricultural purposes can also be employed to oversee and regulate animal welfare on a regional, state, and ultimately global level. In the context of the United States, an example of legislation pertaining to animal transportation for food purposes is the Twenty-Eighth Hour Law. This law imposes restrictions on the duration of interstate transportation for such animals. In contemporary times, this regulation is effectively upheld through the utilization of advanced smart transportation systems that are interconnected via cloud technology. Both domesticated animals and wild animals have experienced advantages from state-of-the-art animal tracking and monitoring systems. According to Article 4 of the European Convention for the Protection of Pet Animals in 1987, it is incumbent upon individuals who possess pets to guarantee that their animals are adequately provided with sustenance, hydration, and physical activity [21]. The advent of GPS and cellular network-based animal trackers has facilitated the monitoring of these responsibilities.

The Animal-Computer Interface (ACI) is an emerging field within the realm of computer science that seeks to support investigations pertaining to animal well-being through the augmentation of communication between humans and animals. The emphasis, conversely, has been placed on the development of non-intrusive monitoring systems for observing the behavior of wild animals, as well as detecting environmental changes that may pose threats to specific species. Additionally, efforts have been made to foster coexistence between humans and animals, encompassing initiatives such as mitigating the risk of vehicular accidents and preventing the threatened species illegal hunting. In order to effectively capture, distribute, and evaluate the significant data volume generated by global biomedical research on animals, it is imperative to employ systems that are founded upon contemporary concepts such as cloud computing, real-time data transmission, and high-performance computing. Currently, there exists a significant motivation to reexamine smart sensing systems and computing for both wild and domestic animals. This is done in order to foster their future advancements and pave the way for innovative advancements in the domain of intelligent models for the health of farm animals. These efforts are undertaken within a shared framework.

Genomics

Genomics research primarily centers on animal genomes, encompassing the investigation of various facets of DNA such as its structural characteristics, functional properties, evolutionary dynamics, and cartographic representation. By offering timely information on the genetic and physical characteristics of individual livestock, it empowers farmers to make informed decisions regarding animal selection and strategic breeding, which can greatly influence future profitability. Farmers stand to gain significant advantages from this development, as it will result in reduced breeding cycles and enhanced genetic traits, thereby augmenting crop yield, quality, and overall survival rates. The preservation efforts of livestock are being significantly influenced by policy changes, shifting weather patterns, and evolving consumer preferences.

The tools and methods for defining and managing Farm Animal Genetic Resources (FAnGR) have undergone significant advancements in the past decade. The management of FAnGR in the context of rapid development poses challenges in terms of maintaining technical consistency, enhancing adopting integrative methodologies, and analytical capacity. Certainly, single-nucleotide high-throughput polymorphism genotyping is manageable for all noticeable farm animal species. Nevertheless, the process of comprehending and interpreting this data within real-world scenarios necessitates the amalgamation of said data with socio-economic and geo-environmental data. This integration poses a significant technological obstacle in its own right.

The European Science Foundation's Research Networking Program "Advances in Farm Animal Genomic Resources" (Genomic-Resources) put forth a proposal to focus on the scientists' education in state-of-the-art methodologies for the analysis, characterization, management, conservation, and evaluation of Farm Animal Genomic Resources (FAnGR) during a span of four years (2010-2014) [22]. The programme aimed to enhance the knowledge and skills of these scientists in this field.The generous funding provided by the RNP facilitated the provision of a total of twenty-six exchange scholarships and three summer schools in Italy, Croatia, and Austria. The aforementioned endeavors convened a group of 350 proficient individuals in their respective domains, with the objective of devising strategies to address two urgent issues: (i) providing comprehensive training to researchers on the utilization of innovative techniques for handling and interpreting high-throughput data for molecules, and (ii) nurturing collaborations between social science and animal science societies to enhance the management of FAnGR.

In addition to the previously mentioned initiatives, Genomic-Resources has published scientific contributions in this edition of Genetics Frontiers that apply novel approaches to bioinformatics and genomic methodologies for FAnGR characterization. These contributions aim to enhance conservation methods for FAnGR both in ex-situ (off-site) and in-situ (on-site) settings. Furthermore, the journal promotes the consideration of socio-economic factors in FAnGR conservation efforts, facilitates lessons transfer from wildlife to biodiversity conservation of biodiversity, and assesses the general FAnGR contribution to a sustainable future.

V. CONCLUSION

Scheduled feeding, limit feeding, full feeding, free access feeding, supplemental feeding are the five most commonly employed approaches for the provision of sustenance to domesticated animals. Thorough assessment of each component is crucial prior to integration into a production system, as these components are specifically designed to cater to distinct processes. If feeding methods are not introduced gradually or are unsuitable, animals may experience adverse health effects, endure long-lasting damage, or potentially succumb to mortality. The implementation of intelligent feeding systems has the potential to enhance agricultural productivity and promote the well-being of cattle across the board. The core of intelligent animal feeding lies in the real-time monitoring and management of feeding operations. The future of agriculture holds promise for individuals who prioritize the enhancement of nutrition, animal welfare, and financial outcomes.

The increasing global demand for meat, dairy, and eggs has led to the implementation of more stringent regulations pertaining to animal welfare and the environmental consequences associated with these industries. The implementation of intelligent feeding practices yields numerous advantages that hold significance for a diverse array of individuals, encompassing both farmers seeking to enhance their agricultural output and farmers residing in developing nations aspiring to diminish their dependence on external food assistance. Enhanced cost-effectiveness, superior quality, sustained uniformity, increased accessibility, and improved traceability will be achieved by all stakeholders across the value chain, encompassing both agricultural producers and ultimate consumers. The industry's negative impact on climate change can be mitigated through the implementation of sustainable practices and the more efficient utilization of natural resources, facilitated primarily by advancements in technology.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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Ethics Approval and Consent to Participate

The research has consent for Ethical Approval and Consent to participate.

Competing Interests

There are no competing interests.

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