PRECISION AGRICULTURE FOR GRAZING AND ANIMAL HEALTH MANAGEMENT: A CASE STUDY IN COLOMBIA

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Abstract

In this research, we address the problem of fattening management and animal health in rotational grazing. For the study of this problem, we have positioned ourselves in the framework of the paradigm of *precision farming*, a technological approach that uses advanced information and communication tools and techniques to optimize agricultural and livestock production processes. In this context, *precision livestock farming* focuses on the use of technologies to improve grazing management and animal health on cattle farms. Some objectives of precision livestock farming are to increase farm efficiency and productivity, improve product quality and reduce production costs. In addition, it also contributes to environmental sustainability by enabling more efficient management of natural resources and reducing negative impacts on the environment. Although precision livestock farming offers many opportunities to improve efficiency and sustainability in livestock production, it also presents challenges that must be addressed for successful implementation. To address this problem, our objective was to develop methodologies, models, and approaches to support decision-making related to productivity management and animal health. To achieve this objective, several sub-objectives were raised, the first one was to develop a precision livestock farming architecture based on emerging technologies (Industry 4.0, artificial intelligence, etc.), the second on developing generic knowledge models of precision livestock farming for animal health and herding management and finally, in the third to develop meta-intelligent models for precision livestock farming in the context of autonomous grazing and animal health management. In general, several research articles were developed to meet the objectives proposed in this thesis. Initially, a review article on the latest trends in precision livestock farming using machine learning techniques was carried out. On the other hand, for the first specific objective, an article was conducted where three autonomous cycles of data analysis tasks based on autonomous computing were proposed for a beef production process for precision livestock farming. To meet the second specific objective, three articles were proposed. The first is a beef cattle weight identification model using machine learning techniques for anomaly detection, the second presented a system for monitoring the cattle fattening process in rotational grazing using fuzzy classification, in the third, a multi-objective optimization model was developed to maximize weight gain of cattle in rotational grazing. Regarding the third objective, three articles were developed, the first one proposed an autonomous cycle of data analysis tasks for the self-supervision of animal fattening in the context of precision livestock farming, and the second article presents a management system for the cattle fattening process in rotational grazing by means of diagnostic and recommendation systems. Finally, the last article proposed the use of the meta-learning paradigm in a cattle weight identification system for anomaly detection. In each article, we evaluated the strategies/models using various datasets. The results showed the capacity of the developed methodologies and models for decision-making in the management of the livestock production process. Specifically, our proposals allow the management of fattening and animal health in rotational grazing, considering, among other things, monitoring, diagnosis, and optimization of the productive process, with good results in performance metrics.

Keywords: Artificial intelligence, Machine learning, Meta-learning, Precision livestock farming, Production management support system, Rotational grazing.

Resumen

En esta investigación, abordamos el problema del manejo del engorde y salud animal en pastoreo rotacional. Para el estudio de este problema, nos hemos posicionado en el marco del paradigma de la *agropecuaria de precisión*, un enfoque tecnológico que utiliza herramientas y técnicas avanzadas de información y comunicación para optimizar los procesos de producción agrícola y ganadera. En este contexto, la *ganadería de precisión* se enfoca en el uso de tecnologías para mejorar la gestión de pastoreo y la salud de los animales en las granjas de ganado bovino. Algunos objetivos de la ganadería de precisión son aumentar la eficiencia y productividad de las granjas, mejorar la calidad de los productos y reducir los costos de producción. Además, también contribuye a la sostenibilidad ambiental, al permitir una gestión más eficiente de los recursos naturales y reducir los impactos negativos en el medioambiente. Aunque la ganadería de precisión ofrece muchas oportunidades para mejorar la eficiencia y la sostenibilidad en la producción de ganado, también presenta desafíos que deben ser abordados para lograr una implementación exitosa. Para abordar este problema, nuestro objetivo fue desarrollar metodologías, modelos y enfoques para apoyar la toma de decisiones en relación con el manejo de la productividad y la salud animal. Para alcanzar este objetivo, se plantearon varios subobjetivos, el primero consistío en desarrollar una arquitectura de ganadería de precisión utilizando tecnologías emergentes (Industria 4.0, inteligencia artificial, etc.), el segundo fue desarrollar modelos de conocimiento genéricos de ganadería de precisión para la gestión de la sanidad animal y el pastoreo, y finalmente, en el tercero desarrollar modelos meta-inteligentes para la ganadería de precisión en el contexto del pastoreo autónomo y la gestión de la sanidad animal. En general, se desarrollaron varios artículos de investigación para cumplir los objetivos propuestos en esta tesis. Inicialmente, se realizó un artículo de revisión de las últimas tendencias de la ganadería de precisión usando técnicas de aprendizaje automático. Por otro lado, para el primer objetivo específico se realizó un artículo donde se propusieron tres ciclos autónomos de tareas de análisis de datos basados en computación autónoma para un proceso de producción de carne de vacuno para la ganadería de precisión. Para cumplir el segundo objetivo específico se propusieron tres artículos. El primero es un modelo de identificación del peso del ganado vacuno mediante técnicas de aprendizaje automático para la detección de anomalías, el segundo presentó un sistema de supervisión del proceso de engorde de ganado en pastoreo rotativo mediante clasificación difusa, y en el tercero se desarrolló un modelo de optimización multi-objetivo para maximizar la ganancia de peso del ganado en pastoreo rotativo. Con respecto al tercer objetivo se desarrollaron tres artículos, el primero propuso un ciclo autónomo de tareas de análisis de datos para la auto-supervisión del engorde de animales en el contexto de la ganadería de precisión, y el segundo artículo presenta un sistema de gestión del proceso de engorde de bovinos en pastoreo rotativo mediante sistemas de diagnóstico y recomendación. Finalmente, el último artículo propuso la utilización del paradigma de meta-aprendizaje en un sistema de identificación del peso del ganado para la detección de anomalías. En cada artículo evaluamos las estrategias/modelos propuestos utilizando diversos conjuntos de datos. Los resultados mostraron la capacidad de las metodologías y modelos desarrollados para la toma de decisión en la gestión del proceso productivo ganadero. Específicamente, nuestras propuestas permiten realizar un manejo del engorde y salud animal en pastoreo rotacional, considerando, entre otras cosas, la supervisión, el diagnóstico, y la optimización del proceso productivo, con muy buenos resultados en las métricas de rendimiento.

Palabras Clave: Inteligencia artificial, Aprendizaje automático, Meta-aprendizaje, Ganadería de Precisión, Sistema de apoyo a la gestión productiva, Pastoreo Rotativo.

Scientific contributions

Several scientific articles were generated and published during the development process of this research project.

Published articles:

- R. García, J. Aguilar, M. Toro, A. Pinto, and P. Rodríguez, "A systematic literature review on the use of machine learning in precision livestock farming" *Computers and Electronics in Agriculture*, vol. 179, p. 105826, 2020. doi.org/10.1016/j.compag.2020.105826
  Q1 Scientific Journal Rankings

- R. García, J. Aguilar, M. Toro, N. Pérez, A. Pinto, and P. Rodríguez, "Autonomic computing in a beef-production process for precision livestock farming", *Journal of Industrial Information Integration*, vol. 31, p. 100425, 2023. doi.org/10.1016/j.jii.2022.100425
  Q1 Scientific Journal Rankings

- R. García, J. Aguilar, M. Toro, and M. Jiménez, "Weight-identification model of cattle using machine-learning techniques for anomaly detection," in *2021 IEEE Symposium Series on Computational Intelligence (SSCI)*, pp. 01–07, 2021. doi:10.1109/SSCI50451.2021.9659840
  In IEEE Xplore

- C. Benitez, R. García, J. Aguilar, M. Jiménez, and H. Robles, "Supervision system of the fattening process of cattle in rotational grazing using fuzzy classification," in *2022 XVLIII Latin American Computer Conference (CLEI)*, pp. 1–10, 2022. doi:10.1109/CLEI56649.2022.9959950
  In IEEE Xplore

Articles submitted to journals:

- R. García, J. Aguilar, "Using meta-learning in a cattle weight identification system for anomaly detection.", preprint submitted to *Computers and Electronics in Agriculture*, 2023.
  Q1 Scientific Journal Rankings

- R. García, J. Aguilar, and A. Pinto, "An autonomous System for the self-supervision of animal fattening in the context of precision livestock farming", preprint submitted to *Future Generation Computer Systems*, 2023.
  Q1 Scientific Journal Rankings

- R. García, J. Aguilar, and M. Jiménez, "A multi-objective optimization model to maximize cattle weight-gain in rotational grazing", preprint submitted to *Annals of Operations Research*,

2022.
Q1 Scientific Journal Rankings

- R. García, J. Aguilar, and C. Benitez, "Management System for the Fattening Process of Bovines in Rotational Grazing using Diagnosis and Recommendation Systems", preprint submitted to *CLEI Electronic Journal*, 2023.
  Scopus

Project context

An internal doctoral grant from Universidad EAFIT has fully funded this study. I am grateful to the Vice-Rectory of Discovery and Creation of Universidad EAFIT for their support in this research. The author thanks the farmers for using their knowledge and experience to build the models and interpret the final results.

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First, I would like to express my deepest gratitude to Almighty God for being my guide and strength throughout this process of researching and writing this thesis. Thank you for your unconditional love and for giving me the wisdom and knowledge necessary to complete this project. I also want to thank you for the health and blessings that have allowed me to continue moving forward, even in the most difficult moments. Thank you for your constant presence in my life and for being my light in the darkness. To you, God, goes my most sincere gratitude.

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Finally, I would like to thank Universidad EAFIT for their financial support during my doctoral studies.

Contents

Chapter 1

Introduction and research context

1.1 Problem statement and motivation

In traditional livestock farming, animal species are raised and products are obtained for human consumption; for example, meat and milk. In total, livestock farming provides 33% of the protein consumed in the human diet [1]. Traditional livestock farming faces several challenges today, including climate change, production costs, demand for healthier products, and ever-changing regulations and standards. To meet these challenges, traditional livestock farming must adapt to changes in the market and the environment, seeking new, more efficient and sustainable forms of production.

Specifically, farmers have to manage the comfort conditions in which the herd (group of animals) is kept. In this sense, climate can influence livestock production in two interrelated ways; the first, in a direct way, called comfort, where the animal achieves the balance of physiological processes with the environment, which favors the utilization of feed; and the second, of indirect action, related to the production and supply of feed, which contributes to the degree of comfort [2]. In addition, an important variable to consider is the animal carrying capacity, i.e., the number of animals that can graze in a paddock without affecting forage productivity. Optimum carrying capacity is defined as that at which production per animal per hectare is maximized. [3]. Animal carrying capacity and optimum carrying capacity are some of the best indicators of a livestock farm's production [4].

Precisely, the success of any livestock farm depends on having a high optimal stocking capacity, which is achieved with an adequate improvement of paddocks, a correct establishment and maintenance of pastures, an effective paddock rotation, and a balanced management of the animal inventory within the farm. In addition to this, it is necessary to consider variables such as soil quality, rainfall and luminosity, which also affect the animal carrying capacity in the farms [5].

Precision Livestock Farming (PLF) offers several opportunities in this context, including the ability to more effectively monitor and control animal welfare, feed efficiency and early detection of disease [5].

This can result in increased productivity and profitability for producers, as well as improved animal care and product quality. In addition, the technology used in PLF can help reduce the environmental impact of livestock production by minimizing resource use and reducing greenhouse gas emissions.

In this work, five particular challenges were identified: i) determination of the optimal stocking capacity, ii) improvement of paddocks with correct pasture establishment and maintenance, iii) effective herd rotation in paddocks, iv) balanced management of animal inventory within the farm and v) consideration of variables such as soil quality that affect animal carrying capacity on farms. These challenges were addressed under the development of a smart management system based on PLF for beef cattle production that considers pasture and animal characteristics.

The implementation of a smart management system based on PLF offers an efficient and sustainable solution to the challenges mentioned above. This system integrates technologies such as sensors, cameras, and remote monitoring systems to collect data on animal welfare, pasture quality and animal carrying capacity. This data is analyzed to make informed decisions and optimize herd management. In addition, it can detect animal health problems early, which can prevent the spread of disease and reduce the need for costly treatments. Thus, our management system represents a solution to the challenges facing traditional livestock farming today.

1.2 Research objectives

1.2.1 General objective

Build a model for the management of livestock production, considering aspects related to animal health and grazing.

1.2.2 Specific objectives

1. Develop a precision-farming architecture based on the integration of precision agriculture and livestock using emergent technologies (Industry 4.0).
2. Develop generic knowledge models of precision livestock farming for animal health and grazing management.
3. Develop a meta-intelligent model for precision farming in the context of autonomous grazing and animal health management.

1.3 Contributions and research scope

This research focuses on the development of models, methodologies, and computational approaches to support decision-making in rotational grazing management. Several contributions were made in this context. The first contribution was a systematic literature review (SLR) to identify challenges and opportunities for precision livestock research [5]. In this review, we focused on two areas of interest: herding and animal health. For each area, we identify three main challenges for precision livestock development in the context of machine learning, sensors and data sources, and data management. For machine learning, the main challenge is to integrate herding and animal health in approaches that allow the development of diagnostic and prescription models for the prevention and control of animal diseases. Moreover, to explore the utilization of autonomous cycles of data analysis tasks. In terms of sensors and data sources, more affordable sensor technologies are needed to measure humidity, temperature, wind, rain, soil quality and animal health status. In terms of data management, the main challenge is the automatic digitization of all useful farm data, followed by measures to reduce energy consumption and improve data presentation in a user-friendly interface.

Based on the SLR, the need to develop a precision agriculture architecture that integrates precision agriculture and livestock farming using emerging technologies was found to be crucial to meet the growing demand for food production while reducing the environmental impact of agricultural practices. The integration of precision livestock and agriculture can also lead to better monitoring and management of animal health and, ultimately, better quality animal products. The development of such an architecture will be key to achieving sustainable and efficient food production in the face of global challenges such as climate change and population growth. To address this problem, an architecture for the self-management of beef production farms was proposed as a step towards sustainable and efficient livestock production [6]. This architecture is based on autonomous cycles of data analysis tasks, which provide real-time monitoring and management of the beef production process, allowing for the detection of anomalies and efficient decision-making.

In addition, the development of generic knowledge models for animal health and herd management is essential to advance the field and enable wider adoption of PLF technologies. These models can serve as the basis for the development of more specific and tailored applications. These models can provide valuable information on animal health and grazing patterns, leading to improved management practices and more efficient use of resources. To abort this problem, we developed a cattle fattening process identification system that can be used to detect anomalies in cattle weight gain over time [7]. The identification system was tested using records of animals raised and fattened at a farm located in Montería, Colombia. Four machine-learning techniques were compared for their performance in identifying the ideal weight from real data, including Decision Tree (DT), Gradient Boosting (GB), K-Nearest Neighbors (KNN) regression, and Random Forest (RF). This system can be a useful tool for livestock entrepreneurs to improve the management of their production and increase their profitability. In addition, a diagnostic system was developed for cattle breeders to diagnose weight loss or gain in cattle under a rotational grazing scheme [8]. The system is based on a fuzzy classifier that uses fuzzy reasoning to determine the current situation of the animal given an input, considering both the health status of the animal and the pasture, and genetic algorithms to optimize the rules that characterize the diagnostic process. The proposed system was tested with experimental cases, with promising results. On the other hand, a multi-objective rotational pasture assignment model was also built to improve cattle feeding, considering the best quality forage and minimizing the distance the animals have to travel from one paddock to another. The model considers the amount of forage available and cattle demand, to dynamically allocate animals to paddocks. The effectiveness of the model was evaluated using a discrete simulation of a one-year cattle rotation, and the results indicated that the average weight gain of cattle was higher with the proposed model compared to the traditional rotation method.

Finally, the development of meta-smart models for PLF in the context of autonomous grazing and animal health management is a crucial step towards achieving sustainable and efficient livestock production. These models can be used to interconnect different datasets from multiple farms, enable automatic digitization of farm data, and develop diagnostic and prescriptive models for diseases. In addition, it can enable autonomous cycles of data analysis tasks to support decision-making for grazing and animal health management. To address this problem, several contributions were carried out. Firstly, an architecture for the self-management of beef production farms was proposed [6]. From this architecture, a first autonomous cycle of data analysis tasks was implemented for the self-supervision of animal fattening. This autonomous cycle provide real-time monitoring and management of the animal fattening process, allowing for the detection of anomalies. Moreover, a self-management system for the cattle fattening process in rotational grazing based on diagnostic and recommendation systems has been proposed. Finally, a meta-learning architecture capable of learning, associating, evaluating, and adapting to new data was developed. The use of meta-learning improved the performance of the anomaly detection process by continuously updating the knowledge base with each successful adaptation.

All the contributions made in this research are represented in several research articles. A total of six (8) scientific articles were generated, of which four (4) are published and the other four (4) are under review.

1.4 Thesis organization

This thesis is presented as a collection of articles developed to meet each of the proposed objectives. In Chapter 2, we conducted an SLR on PLF, which allowed us to collect and evaluate relevant existing information in this field. It identifies the main trends and approaches, as well as knowledge gaps and challenges that still need to be addressed. Chapter 3, Chapter 4, and Chapter 5 correspond to the fulfillment of the first, second and third objectives, respectively. One article was generated for the first objective, three articles for the second objective, and three articles for the last objective. These articles will be presented in each section.

In summary, in Chapter 2, we show an SLR useful for identifying trends, challenges, and research opportunities in PLF using machine learning. Chapter 3 shows an architecture for PLF with autonomic properties fulfilling the objective 1. Moreover, in Chapter 4, three articles corresponding to the second objective proposed in this thesis are presented. The first article corresponds to the development of a cattle weight identification model using machine learning techniques for anomaly detection. The second article corresponds to the development of a system for monitoring the beef cattle fattening process in rotational grazing utilizing fuzzy classification. The third article corresponds to a multi-objective optimization model to maximize the weight gain of cattle in rotational grazing. For Chapter 5, we present three articles corresponding to the third objective proposed in this thesis. In the first article, an autonomous self-monitoring system for animal fattening in the context of PLF was developed. The second article developed a management system for the cattle fattening process in rotational grazing using diagnostic and recommendation systems. The last article presents the use of meta-learning techniques for a livestock weight identification system for anomaly detection. Through meta-learning, the system can adapt and learn from data from multiple farms and environments, improving its performance and accuracy over time.

Finally, in Chapter 6 presents a summary of the conclusions of all the papers presented in the previous sections. Finally, in this section, we show the limitations of our research and possible future work.

Chapter 2

State of the art of machine learning in precision livestock farming

2.1 Motivation

In this chapter, we present an SLR that aims to provide a comprehensive overview of the recent advances and applications of machine learning in PLF, with a focus on grazing and animal health. The literature review highlights the potential of machine learning to transform the livestock sector and improve animal welfare. The current use of sensors, software, and techniques for data analysis is also discussed, along with the increasing openness of data sources.

The findings of the review indicate that the use of machine learning in precision livestock farming is still in its early stages of development and faces several research challenges. These challenges include developing hybrid models for the diagnosis and prescription of animal diseases, integrating grazing and animal health issues, increasing the autonomy of precision livestock farming through autonomous data analysis cycles and meta-learning, and bringing together soil and pasture variables for a better understanding of both animal health and grazing behavior. The whole article is in Appendix A.

2.2 Identification of the article

R. García, J. Aguilar, M. Toro, A. Pinto, and P. Rodríguez, "A systematic literature review on the use of machine learning in precision livestock farming" Computers and Electronics in Agriculture, vol. 179, p. 105826, 2020. Q1 Scientific Journal Rankings

2.3 Abstract

This article presents a systematic literature review of recent works on the use of machine learning (ML) in precision livestock farming (PLF), focusing on two areas of interest: grazing and animal health. This review: (i) highlights opportunities for ML in the livestock sector; (ii) shows the current sensors, software, and techniques for data analysis; (iii) details the increasing openness of data sources. It was found that the use of ML in PLF is in a stage of development and has several research challenges. Examples of such challenges are: (i) to develop hybrid models for diagnosis and prescription as a tool for the prevention and control of animal diseases; (ii) to bring together the grazing and animal health issues; (iii) to give autonomy to PLF using autonomous cycles of data analysis tasks and meta-learning; and (iv) to bring together soil and pasture variables because, for both, animal health and animal grazing, the variables used are only behavioral and environmental.

2.4 Link to the full article

https://doi.org/10.1016/j.compag.2020.105826

Chapter 3

Autonomic architecture for beef-production processes

3.1 Motivation

The goal of an autonomic computing architecture in beef production is to reduce the need for manual intervention, improve the accuracy and speed of decision-making, and ultimately, lead to more efficient and sustainable production processes. In this context, this architecture would provide the ability to self-manage, self-configure, self-optimize, and self-heal in real-time, enabling the system to continuously monitor and adjust various aspects of the production process, such as feed, water, and health management, in response to changing environmental and animal health conditions. Additionally, it would provide real-time monitoring and analysis of data, such as animal weight and growth, to allow farmers to make informed decisions about their production processes and improve the overall welfare of their animals. Thus, in this chapter, we present the first paper for the fulfillment of the first objective. The whole article is in Appendix B.

3.2 Identification of the article

R. García, J. Aguilar, M. Toro, N. Pérez, A. Pinto, and P. Rodríguez, "Autonomic computing in a beef-production process for precision livestock farming," Journal of Industrial Information Integration, vol. 31, p. 100425, 2023.

3.3 Abstract

Precision livestock farming (PLF) offers farmers real-time monitoring and management system. PLF provides a real-time warning when something goes wrong so that the farmer can take immediate action to solve the problem. PLF introduces many new challenges and questions that must be resolved. Some of these challenges are related to the integration of grazing and animal health into the beef-production process. This article introduces an architecture for the self-managing of a beef-production farm. In particular, the architecture includes three autonomous cycles of data analysis tasks (ACODAT) that allow beef producers to have adequate coordination, optimization and planning of the productive process, which are: (i) circuit preparation, (ii) animal purchase, and (iii) animal fattening. This article also instantiates, in a farm, the autonomous animal-fattening cycle, as the first step towards efficient and effective beef-production processes. The main contributions of this architecture are (i) the ability to use everything mining to improve the knowledge of the system and decision-making processes, and (ii) three ACODAT for real-time analysis for sustainable and environmentally-friendly livestock production. The results are encouraging since the ACODAT allows smart management of the beef-production process, naturally introducing artificial-intelligence techniques to develop these tasks. Particularly, modeling using ACODAT allows an adequate description of a precision livestock process. Likewise, the preliminary results of some of the tasks of ACODAT are stimulating because they allow evaluating the feasibility of the proposal. For example, a first task for the identification of cattle fattening has a Mean Absolute Error (MAE) of 5.4 kg, which will be used by ACODAT to identify anomalies in the fattening process. The instantiation of the animal-fattening cycle shows the viability and robustness of this proposal.

3.4 Link to the full article

https://doi.org/10.1016/j.jii.2022.100425

Chapter 4

Knowledge models for precision livestock farming

4.1 Motivation

PLF involves the use of technology to monitor and manage the health, nutrition, and behavior of cattle, among other things. The use of knowledge models in this process can help farmers to make data-driven decisions that lead to improved productivity, profitability, and animal welfare. Knowledge models can be used to analyze large amounts of data, identify patterns, and make predictions, among other things, which can then be used to optimize feeding and grazing strategies, disease control, and waste management. With the increasing demand for high-quality and sustainable food production, building knowledge models for PLF is becoming an important aspect of modern agriculture.

Thus, in this chapter, we present three articles to fulfillment the second objective. The first article presents one knowledge model for weight identification of cattle. The second article presents a second knowledge model for the supervision of the rotational grazing cattle fattening process. Finally, the last article describes an assignment model for maximizing weight gain of rotationally grazed cattle.

4.2 Weight-identification model of cattle

4.2.1 Motivation

The motivation of the livestock weight identification model using machine learning techniques for anomaly detection is to improve the efficiency and accuracy in identifying animals with out-of-normal weight in the livestock industry. By using machine learning techniques, the model can learn and adapt to different situations and conditions, allowing faster and more accurate detection of cattle weight anomalies. This can help farmers and ranchers identify health or nutritional problems in livestock earlier, which in turn can improve the quality and yield of livestock production. Thus, in this section, we present the first article to fulfillment the second objective. The complete article can be found in Appendix C

4.2.2 Identification of the article

R. García, J. Aguilar, M. Toro, and M. Jiménez, "Weight-identification model of cattle using machine-learning techniques for anomaly detection", in 2021 IEEE Symposium Series on Computational Intelligence (SSCI), pp. 01–07, 2021.

4.2.3 Abstracts

Cattle raising is an important economic activity, where livestock entrepreneurs keep track of their production and investment costs, to measure production and business profitability, based on cattle weighing. But it's hard for the farmer to tell if the animals they're weighing have gotten the right weight. This paper proposes a framework to identify the fattening process, which can be used to detect anomalies in cattle weight-gain over time. This framework used records of animals raised and fattened at "El Rosario" farm, located in the municipality of Montería (Córdoba-Colombia), to identify the fattening process. The performance of four machine-learning techniques to identify the ideal weight from real data was compared. The algorithms used were Decision Tree (DT), Gradient Boosting (GB), regression based on K-Nearest Neighbors (KNN), and Random Forest (RF). In addition, an outlier-detection process was performed to identify anomalous weights. In general, the results showed that the DT model was the one with the best performance, with an average Mean Absolute Error (MAE) of 5.4 kg.

4.2.4 Link to the full article

https://doi.org/10.1109/SSCI50451.2021.9659840

4.3 Supervision system of the rotational grazing cattle fattening process

4.3.1 Motivation

The motivation of the supervision of the rotational grazing cattle fattening process using fuzzy classification is to improve efficiency and accuracy in monitoring cattle health and growth during the rotational grazing fattening process. By using fuzzy classifiers techniques, the system can adapt to different environmental and grazing conditions, allowing for more accurate and timely monitoring of cattle. This can help farmers and ranchers detect health problems in livestock earlier, make informed decisions about nutrition and grazing management, and improve the quality and yield of livestock production. Thus, in this section, we present the second article to fulfillment the second objective. The complete article can be found in Appendix D.

4.3.2 Identification of the article

C.Benitez, R.García, J.Aguilar, M.Jiménez, and H.Robles, "Supervision system of the fattening process of cattle in rotational grazing using fuzzy classification", in 2022 XVLIII Latin American Computer Conference (CLEI), pp. 1–10, 2022.

4.3.3 Abstracts

Cattle breeding has been one of the most important industrial sectors in the world, since it is related to food security and the survival of the human race. Cattle diagnostics is a fundamental procedure for cattle breeders because it allows them to make strategic decisions, such as timely treatment in case of any abnormality (e.g., weight gain in herds, in their paddocks). This article aims to present a system to diagnose weight loss or gain in cattle under a rotational grazing scheme, considering the health status of the animal and the pasture. The diagnostic system is based on a fuzzy classifier that uses fuzzy logic to define the rules that characterize the diagnostic process, and fuzzy reasoning to determine the current situation given an input. In addition, the fuzzy classifier optimizes the rules using genetic algorithms, which modify the membership functions, providing a more accurate system for diagnosis. We tested our proposal with experimental cases, with promising results. The accuracy metrics have high values, indicating a low error rate in terms of false positives. In general, the values of the quality metrics are good, with an accuracy close to 100% and an Area Under the Curve close to 1.

4.3.4 Link to the full article

https://doi.org/10.1109/CLEI56649.2022.9959950

4.4 Assignment model for maximizing weight gain of rotationally grazed cattle

4.4.1 Motivation

The motivation of the multi-objective optimization model for maximizing weight gain of rotationally grazed cattle is to improve the efficiency and profitability of livestock production. By using optimization techniques, the model can find the optimal combination of factors such as livestock density, grazing duration, grass quality, nutrition, and other relevant factors to maximize weight gain of rotationally grazed cattle. This can help farmers and ranchers maximize meat production and reduce costs. In addition, the optimization model can also be useful in improving the sustainability of livestock production by optimizing the use of available resources and reducing the negative environmental impacts associated with intensive livestock production. Thus, in this section, we present the third article to fulfillment the second objective. The complete article can be found in Appendix D.

4.4.2 Identification of the article

R. García, J. Aguilar, and M. Jiménez, "A multi-objective optimization model to maximize cattle weight-gain in rotational grazing", preprint submitted to *Annals of Operations Research*, 2022.

4.4.3 Abstracts

Rotational grazing can improve cattle feeding considering a series of aspects, such as: (1) the maximum utilization of each hectare of pasture on which the cattle are fed and; (2) the pasture analysis to guarantee the type and the size of the pasture that will serve as feed, among others. The above aspects allow a better-fed cattle, with better weight and meat quality. To implement rotational grazing, it is necessary to carry out forage-utilization practices with criteria associated with the morphophysiology and phenology of the forage species. Many of these data, in the real context of a beef farm, are not used, and most of the decisions made by the farmer are based on experience (successes and failures in productivity). In this proposal, we establish a multi-objective rotational-grazing assignment model based on (1) the best quality forage, and (2) the distance an animal must travel from one paddock to another. At each stage, we estimate the amount of forage as well as the total weight of each batch of animals. Based on pasture yield and cattle forage demand, we propose a dynamic assignment model. To validate the effectiveness of the assignment model, we carried out a discrete simulation of a one-year cattle rotation. Results show that the assignment model generates a statistically higher average weight gain than the one generated by the traditional rotation method.

4.4.4 Link to the full article

See Appendix D.

Chapter 5

Meta-intelligent models for precision farming

5.1 Motivation

The need to develop meta-intelligent models in all areas of artificial intelligence has become a great challenge, either due to the need to make systems more adaptable, or to give them greater autonomy in the processes where they intervene. This does not escape the area of PLF, in such a way as to give a greater degree of intelligence to the processes managed in this context. In this regard, in this chapter, the concept of autonomous cycles of data analysis was used to confer autonomy to various livestock management processes, which are presented in the first section of this chapter. Subsequently, a meta-learning model was proposed to adapt one of the knowledge models presented in the previous chapter, the weigh-identification model, to different data sources.

5.2 Autonomous systems in the context of precision farming.

5.2.1 Autonomous system for the self-supervision of animal fattening

5.2.1.1 Motivation

Autonomous systems for self-monitoring animal fattening aim to improve efficiency and accuracy in the monitoring and management of livestock fattening. By utilizing automation and monitoring technologies, the system can provide constant and accurate monitoring of livestock weight, nutrition, and health without the need for constant human intervention. This can help farmers and ranchers detect health problems in cattle earlier, optimize nutrition and fattening management, and improve the quality and yield of livestock production. In addition, the autonomous system can also be useful in reducing the costs associated with manual livestock monitoring and improving the sustainability of livestock production by optimizing the use of available resources and reducing the negative environmental impacts associated with intensive livestock production. Thus, in this section, we present the first article to fulfillment the third objective. The complete article can be found in Appendix F.

5.2.1.2 Identification of the article

R. García, J. Aguilar, and A. Pinto, "An autonomous System for the self-supervision of animal fattening in the context of precision livestock farming", preprint submitted to *Future Generation Computer Systems*, 2023.

5.2.1.3 Abstract

Beef production needs certain levels of autonomy to ensure that animal fattening processes achieve certain sustainability objectives (e.g., financial and environmental). For example, it is required oversight in the animal fattening process, so that stakeholders can make better decisions about what is happening in the fattening process. For monitoring the animal fattening process, this paper proposes an autonomous system. In this paper, this autonomous system is designed and implemented using the methodology for the development of data mining applications called MIDANO, and is tested in a cattle farm simulator that has been developed to reproduce the events of the animal fattening production process. This autonomous system for the self-supervision of the animal fattening process is composed of two data analysis tasks, one to detect anomalies in the fattening of cattle, and another to diagnose this anomaly. The results with real data demonstrate the ability of the proposed supervision system to detect and diagnose anomalies in various conditions (normal, animal health problems, and forage problems in the paddock), and the possible causes of abnormal values in the weight variable. The anomaly detection models have a MAE of the order of 5 kilograms, and the diagnostic model has 95% of Accuracy and 1 of AUC. The results of the experiments are encouraging, as they show that the autonomous system is capable of detecting anomalies and diagnosing them in different operating scenarios. Our system allows giving self-supervision characteristics to a production process.

5.2.1.4 Link to the full article

See Appendix F.

5.2.2 Self-management system of the cattle fattening process

5.2.2.1 Motivation

Improving the efficiency of the cattle fattening process is presented through the development of a management system that takes into account both animal health and pasture quality in the field. This is critical for cattle breeders, as it allows them to make strategic decisions and timely treatments in case of any abnormalities, which in turn improves growth and meat quality while minimizing environmental impact. The proposed system is based on artificial intelligence techniques, such as fuzzy systems and genetic algorithms, for diagnosis, and for pasture recommendation, a classification model, which allows for greater accuracy and efficiency in decision-making. Thus, this section presents the second article to fulfillment the third objective. The complete article can be found in Appendix G.

5.2.2.2 Identification of the article

R. García, J. Aguilar, and C. Benitez, "Management System for the Fattening Process of Bovines in Rotational Grazing using Diagnosis and Recommendation Systems", preprint submitted to *CLEI Electronic Journal*, 2023.

5.2.2.3 Abstract

Cattle breeding has been one of the most important industrial sectors in the world, since it is related to food security and the survival of humanity. Management of the cattle fattening process is a fundamental procedure for cattle breeders because it allows them to make strategic decisions, such as timely treatment in case of any abnormality (e.g., weight gain in herds, in their paddocks). This article aims to present a management system for the cattle fattening process under a rotational grazing scheme, considering the health status of the animal and the pasture, which should diagnose weight loss or gain in bovines and recommend actions when is required. The diagnostic process is based on a fuzzy system that defines rules that characterize the diagnostic process to determine the current situation given an input. Furthermore, the fuzzy classifier optimizes its rules by means of genetic algorithms by modifying its membership functions, providing a more accurate system for diagnosis. On the other hand, the recommendation system is based on a classification model of pasture crops, in which the best pasture is recommended given the soil variables. We tested our proposal with experimental cases, with promising results. For the fuzzy classifier, the accuracy metrics are good, with values of accuracy close to 100% and of Area Under the Curve close to 1. For the classification model were used several machine learning techniques, resulting in the best classifier the random forest technique, with an accuracy of 98.61%.

5.2.2.4 Link to the full article

See Appendix G.

5.3 Meta-Learning in the context of PLF

5.3.1 Motivation

The motivation for using Meta-Learning in the context of PLF is to continuously improve the accuracy and performance of the decision-making system over time. This can be achieved by updating the knowledge base of the system with new data and experiences, or by allowing the system to adapt and learn from past successes and failures. In PLF, by using Meta-Learning, a system can continuously improve its accuracy and performance to identify patterns and anomalies in the fattening process based on previous observations. Specifically, it can learn from previous experiences (for example, learned on other farms) and unlearn from outdated models to update them. This section presents the third article to fulfillment the third objective. The complete article can be found in Appendix H.

5.3.2 Identification of the article

R. García, J. Aguilar, "Using meta-learning in a cattle weight identification system for anomaly detection.", preprint submitted to *Computers and Electronics in Agriculture*, 2023.

5.3.3 Abstract

Weighing management in cattle farming is important for farmers, as it allows them to accurately monitor the growth and development of their animals. It is also a valuable tool that allows farmers to maximize production and the welfare of their animals. However, it is difficult for the farmer to detect if the herd of animals being weighed is gaining the ideal weight for a given breed and age. In addition, normally, when a new breed of cattle is introduced to a farm, there is very little data. This article proposes a meta-learning framework (MTL) for identification models used in the fattening process of animals to detect anomalies in cattle weight. The proposed MTL framework has a knowledge base of Meta-Models on Identification models based on machine learning techniques, which is used to select the identification model to use when a new breed of cattle arrives on the farm. This knowledge base is updated, either because a previous identification model has been successfully adapted to the new breed, or a new identification model has had to be generated, allowing the framework to continuously improve its performance over time. Particularly, this article presents in detail the process of adaptation of the previous identification models to new breeds carried out by our MTL framework. Besides, to test our approach a case study is presented, using records of animals raised and fattened at the "El

Rosario" farm, located in the municipality of Monteria (Córdoba-Colombia). The results are very encouraging in terms of the ability of our framework to adapt the identification models to different possible scenarios in a process of detecting anomalous weights. In general, the identification models generated with our proposal had an R^2 of 90.8%, which suggests that the models can explain the variability observed in the data.

5.3.4 Link to the full article

See Appendix H.

Chapter 6

Conclusions

In this chapter, we present a summary of the results of all the work presented above. In addition, we show limitations and research opportunities for the future.

6.1 Summary

As a first main conclusion, in our systematic literature review, we highlight the current state of the art of machine learning techniques used in precision livestock for herding and animal health monitoring. Most of the works focus on sheep and cattle, using classification techniques to analyze animal behavior and variables such as feeding behavior. However, there are still important limitations in the use of variables, as soil variables and animal production factors are not adequately considered. In addition, most animal health studies have focused on monitoring animal behavior with classical Machine Learning techniques for classification, and there is no work on diagnosis, prediction, or prescription of treatments for diseases. We identify the urgent need to address these limitations that can incorporate different variables and production management to improve the efficiency of precision livestock farming.

To assist farmers in these tasks, we developed a precision farming architecture, which integrates and interoperates different actors in the context of PLF. We include autonomous self-planning cycles that can adapt to new environmental constraints and changes in forage demand. We also highlight the use of mining techniques as a key factor in decision-making processes. Furthermore, we present a case study of rotational grazing as an example of how to incorporate self-management into a beef production process.

In addition, we developed generic knowledge models based on data mining and artificial intelligence for animal health and grazing in the PLF context. Particularly, an identification model for detecting anomalies in beef cattle fattening processes. The model yields promising results in detecting anomalous observations of cattle body weight, which is an effective solution for the beef production industry. Furthermore, the developed diagnostic system, based on fuzzy logic and genetic algorithms, it has proven to be an effective tool for diagnosing weight loss or gain of cattle in rotational grazing regime. Finally, the rotational pasture allocation model developed is a tool that maximizes the use of each hectare of pasture and considers the distance traveled by each animal. The results indicate that the model generates a higher average weight gain than the traditional rotational method.

Importantly, meta-intelligent precision livestock modeling in the context of autonomous grazing and animal health management is a novel approach to developing adaptive knowledge models for meat production, which allows systems to continuously improve performance over time. For example, our meta-learning model uses a knowledge base of machine learning models to detect anomalies in animal weights, and updates with each successful adaptation to improve performance. This allows ay continuous learning process from the data, which translates into greater efficiency and profitability for producers. In addition, we developed an autonomous system for managing the animal fattening process in rotating paddocks, which includes a fuzzy diagnostic system and a recommendation system based on a grass classifier model. The system has potential to be used in livestock disease diagnosis and paddock performance optimization. We also developed a self-monitoring system to detect and diagnose anomalies in animal weight. The system combines several machine learning techniques to achieve its objectives, being flexible and adaptable. The results indicate that the system is effective in detecting and diagnosing anomalies.

In general, the results of the experiments are encouraging, as they show that our different propositions can plan, monitor, identify, detect and diagnose, among other things, in different operational scenarios, allowing better decisions to be made in meat production.

6.2 Limitations and future work

We developed strategies or approaches to support decision-making in grazing and animal health management. With the results of the present research, we were able to meet the proposed objectives.

However, this research has some limitations, particularly, in the precision agriculture architecture based on the integration of agriculture and livestock using emerging technologies. One of the main limitations of the proposed architecture is the cost associated to the sensors for data acquisition, which can be a major obstacle to its implementation [9, 10]. In addition, ensuring optimal sensor distribution, stable power flow, and internet connectivity in farms, may also pose a challenge [11]. Another potential limitation is the assumption that the ideal grazing plan for a specific breed of cattle is similar in different contexts, which may not always be the case [12].

Furthermore, in the development of generic knowledge models for animal health and grazing in the contexto of PLF; it is only applicable to rotational grazing, the cattle population must be from the tropics, and 2 climatic seasons (summer and winter) were evaluated. Therefore, this system can only be used in contexts with the following characteristics: in farms that use rotational grazing, regardless of the size of the cattle herds, and that the climatic seasons are summer and winter (for the tropics) where winter is rainy and summer is dry. It is important to note that this system may not be applicable to farms with different management practices, or in regions with different climatic conditions.

Additionally, for the development of meta-intelligent models in the context of PLF for the autonomous grazing and animal health management, it requires a large amount of data to train the initial models. Also, it is assuming that ideal weight growth curves for specific breeds of cattle are similar in all contexts. Moreover, our architecture may not be suitable for farms that do not have access to data analysis tools.

Future work on the architecture of precision agriculture based on the integration of agriculture and livestock using emerging technologies could be directed at developing an optimal sensor distribution model, to obtain an adequate and sufficient coverage of the area to be monitored. If sensors are not properly distributed, critical data may be lost or the quality of the data collected may be low, which may compromise the effectiveness of the livestock production monitoring and management system.

Moreover, in the development of generic knowledge models for animal health and herding based on fuzzy classifiers, it is possible to extend the process of rule adaptation (currently only based on trapezoidal membership functions). For example, allowing other membership functions (e.g., Gaussian), or even, the possibility of making changes in the variables used in the rule antecedent. Along the same lines, other possible extensions are to use more context variables (e.g., explicitly the weather in the antecedents), or to allow varying the number of fuzzy sets in the fuzzy variables (e.g., more or fewer states to characterize the fattening process).

In the context of our meta-learning architecture, to test different synthetic data generation algorithms for the PLF context and evaluate their performance and behavior in our architecture, is a future work. In addition, to incorporate prescription models to define how to act in case an anomaly is diagnosed in the meat production process is a future extension to our autonomic cycles.

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Appendix A

A systematic literature review on the use of machine learning in precision livestock farming

Appendix B

Autonomic computing in a beef-production process for precision livestock farming

Appendix C

Weight-identification model of cattle using machine-learning techniques for anomaly detection

Appendix D

Supervision system of the fattening process of cattle in rotational grazing using fuzzy classification

Appendix E

A multi-objective optimization model to maximize cattle weight-gain in rotational grazing

Appendix F

An autonomous System for the self-supervision of animal fattening in the context of precision livestock farming

Appendix G

Management System for the Fattening Process of Bovines in Rotational Grazing using Diagnosis and Recommendation Systems

Appendix H

Using meta-learning in a cattle weight identification system for anomaly detection