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Livestock IoT: Precision Livestock Management in Agribusiness

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ABSTRACT

This paper introduces Livestock IoT (LIoT), a Software Ecosystem (SECO) tailored for precision livestock management within the broader Internet of Things (IoT) concept in agribusiness. In response to the challenges posed by the Fourth Industrial Revolution and the need for enhanced productivity in global food production, the paper highlights the transformative emergence of IoT in elevating precision agribusiness. LIoT is designed to capture, store, and interpret data, providing an integrated platform for intelligent decision-making in animal treatment and automated events. The SECO is structured into five layers, including data streaming, processing, integration, external sources, and visualization, offering a holistic view of information related to confined livestock farming. The paper presents an initial evaluation of the SECO LIoT platform, demonstrating its efficacy in handling compost barn data and supporting decision-making in agriculture. Future work is outlined to optimize the architecture, explore novel applications, and enhance its capacity for supporting emerging technologies in precision livestock contexts.

KEYWORDS

livestock, farming, cows, agriculture, animals, sensors

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1 INTRODUCTION

In the ever-evolving landscape of agribusiness, a sector integral to global food production, the imperative for enhanced productivity and superior product quality has gained paramount significance. As the global population is anticipated to burgeon to 9.6 billion by 2050 [6], the agribusiness sector faces an unprecedented challenge to meet burgeoning food demands [7]. Precision and adaptability have become imperative in this context, where the consequences of inadequate monitoring resonate from individual farms to entire national economies.

Within agribusiness, livestock production stands as a linchpin, susceptible to a myriad of variables that impact animal well-being and overall productivity. The intricate dynamics of factors such as humidity and temperature in the production environment necessitate meticulous control to avert diseases and inflammation, ensuring optimal production outcomes [5]. To address these challenges, modern agribusiness Production Systems (PS) are increasingly incorporating a blend of software-based solutions and manual labor. This amalgamation serves to monitor, self-regulate, automate actions, and predict unfavorable conditions, thereby fortifying the sector against potential setbacks [4].

The transformative emergence of the Internet of Things (IoT) has proven pivotal in elevating precision agribusiness, evident in the proliferation of over 20.8 billion IoT-connected devices globally. This surge in adoption, reflected in the $742 billion worldwide market in 2020, extends its transformative applications to diverse sectors [2], including its recent integration into agribusiness. The resulting synergy between producers and IoT technologies has bridged gaps, facilitating more informed and efficient decision-making.

In that direction, we can foresee the inadequacy of prevailing Software Engineering practices in addressing the challenges posed by digital transformation within the scope of the Fourth Industrial Revolution. Particularly within the specific context of livestock

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farming, which involves working with living beings as part of its production process, distinct requirements and applications are necessitated, differing notably from other production activities.

In our preceding investigation [7, 11], we engaged in a comprehensive exploration of the Internet of Things (IoT) applications in precision agriculture. In that investigation, adopting a systematic mapping approach, meticulously analyzed 35 primary works specifically focused on IoT-based software systems tailored for precision agribusiness. The primary objective was to systematically categorize both the benefits and challenges inherent in this domain, aiming to strategically position and stimulate new research endeavors. The outcomes of the study yielded valuable insights into a diverse range of platforms and agribusiness activities utilized throughout the entire agribusiness life cycle. Noteworthy were the accessible and cost-effective solutions presented, leveraging technologies such as Arduino and Raspberry. Concurrently, the study underscored challenges related to integration, adaptability, and interoperability.

Building upon these insights, the primary goal of this research is to extend the inquiry and introduce a Software Ecosystem (SECO) that distinguishes the livestock vertical under a broader IoT concept with unique requirements, applications, target audience, and strategy. A SECO, defined as a set of actors and artifacts internal and external to an organization or community, interacting on a common technological platform [13], has overarching impacts on business models, architectural decisions, governance, and collaboration models throughout the software life cycle. The integration of IoT devices into an SECO focused on livestock farming business models can yield substantial benefits, leveraging information from these devices and integrating SECO applications to provide a holistic view of livestock business models.

In this context, the proposed project aims to develop a SECO platform, called LIoT, designed to capture, store, and interpret data. LIoT serves as a common platform shared by a set of applications, allowing for an integrated view of information and services within the platform. This integrated and holistic perspective facilitates intelligent decision-making in the treatment of animals and, consequently, the execution of automated events.

The remainder of this paper is structured as follows: Section II brings an overview on the SECO LIoT platform, Section III presents results of an initial evaluation, and Section IV concludes the paper pointing for future work.

2 RELATED WORK

In the realm of smart farming, researchers have explored the integration of meteorological data with intelligent prediction models in agriculture.

Parrott et al. [12] introduced a multi-agent collaborative architecture for dairy industry decisions, utilizing ontology for cross-domain communication. In contrast, our work integrates data directly, employing inference algorithms like Pellet for knowledge discovery. This enhances the integration process by establishing new connections among information sources.

Janssen et al. (2009) [8] presented the SEAMLESS architecture, integrating databases across climatic conditions, soil, and cropping patterns. In comparison, our work not only enables knowledge integration but also facilitates its discovery and sharing among diverse research centers.

In turn, Jonquet et al. [9] introduced AgroPortal, a platform aligning ontologies for data reuse in agricultural software applications, our approach goes beyond by using ontologies as integration models and data provenance for experiment reuse.

Kamilaris et al. [10] proposed Agri-IoT, a semantic framework for IoT-based smart farming, primarily focusing on extracting semantic knowledge from information and ontologies. Our work extends this by incorporating intelligent algorithms for data processing, surpassing semantic description to address relationships between data.

Anbananthen et al. [1] contribute a decision support system employing hybrid machine learning technologies. However, a comprehensive exploration of how these technologies support agricultural actions is lacking, limiting the practical applicability of their approach.

Studies supporting decisions on soil-related matters predominantly employ machine learning techniques, predicting soil quality, crop selection, and disease outbreaks. Yet, they exhibit limitations concerning scalability, adaptability to changing conditions, and flexibility in incorporating diverse data types.

In addressing these gaps, our work integrates semantics and machine learning to enhance algorithm training and decision-making concerning climate data, diseases, and other external variables. This comprehensive approach aims to enrich complex decisions in agribusiness.

Notably, existing studies do not explore or utilize the support of a SECO platform for deriving specific architectures tailored to support diverse agricultural experiments. Consequently, the literature lacks discussions on solutions for deriving agricultural architectures within an "ecosystem platform" context, particularly for livestock.

3 SECO LIOT PLATFORM

A Software Ecosystem (SECO) constitutes an integration of solutions and services sharing market, resources, and software solutions, providing environments tailored to diverse user needs [13]. This inclusivity leads to advantages such as heightened resource value, user attractiveness, and accelerated innovation. Constructing an ecosystem platform within the Agribusiness context necessitates consideration of quality attributes, specifically extensibility for modular additions and scalability for evolving functionalities. The emphasis on interoperability facilitates collaboration across distinct farm contexts, enabling shared experiences to inform decisions concerning animal health.

Figure 1 offers a general and abstract portrayal of a SECO designed for confined livestock farming, where IoT devices play a pivotal role in data capture. The SECO, named LIoT (Livestock IoT), strives to furnish an integrated platform that facilitates the combined utilization of data and services. This integrated approach aims to enhance decision-making processes related to animal health within the context of confined livestock farming.

The platform is structured into five main layers. Each layer provides a set of specific services to support related applications. The first consists of collecting streaming data from IoT devices in real-time. The processing layer manages and processes the collected

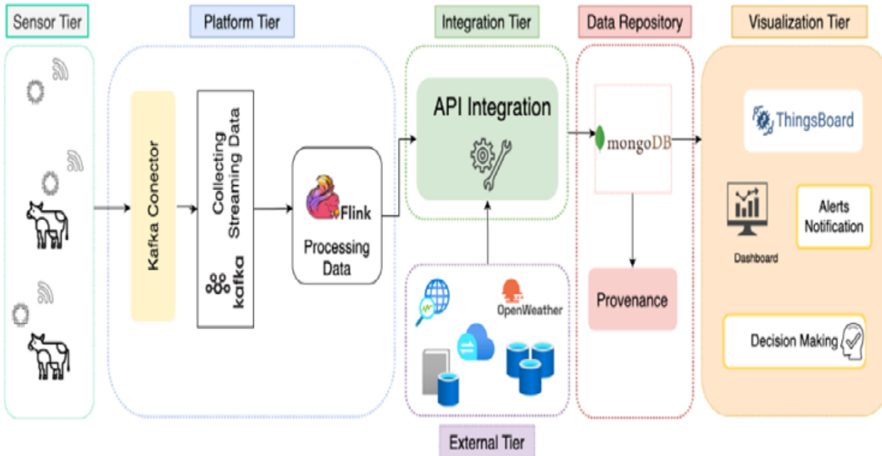

Figure 1: LIoT Platform Overview.

data, promoting an integrated view of them, based on the interrelationship of data coming from different devices. The integration layer has the role of aggregating data from external services and context, such as meteorological data and weather forecasts. The external services layer comprises other sources, databases and services and, finally, the visualization layer, which aims to allow applications to use the services provided by the platform, as a way of assisting in decision making. All five layers are presented below:

- **Data streaming layer**: aggregates all sensors present in the physical space of the compost barn, whether devices installed on animals or in the environment. In addition to data coming from IoT devices, data from different sources and services and with different natures can be aggregated, including text files and spreadsheets. To collect streaming data, we use a specific wrapper, represented in Figure 1 as "Kafka Connector". This wrapper provides an interface for data entry into the system. Different devices and services can be integrated into this layer, such as external environmental data services as well as services for selective data processing.
- **Processing layer**: This layer is responsible for processing the collected data and integrating them, considering the relationship between them. This layer can use specific services such as ontological processing or the use of intelligent algorithms to integrate data, generating new knowledge. Thus, ontology processing services, services related to the processing of Machine Learning algorithms, among others, may be part of this layer. Figure 2 presents, as an example, a partial view of an ontology model for the dairy cattle domain. The entities represent animals, agents are the farmers, and activities are any action carried out on the farm. Activities can be described as insemination, milking, or processing data. With this model, it is possible to identify the data sources and the interactions that farmers and researchers carry out. As a result, it is possible to track decisions related to these specific activities. It is important to note that the ontological model must be connected to the specific agricultural domain where the sensors are used, i.e., the ontological model must be related to this specific context if we want to support actions on a grain PS. Moreover, we can derive new relationships between data and discover further information from SWRL rules (Semantic Web Rule Language) and inference algorithm processing.
- **Integration Layer**: this part is responsible for receiving and integrating the data processed by the sensors. The integration layer can also aggregate information from other repositories, services and external APIs. The main advantage of this layer is being able to integrate and store heterogeneous data in an integrated manner, providing a holistic view of it so that it can be used by the platform's services and applications. This layer is also related to data traceability, since the data will be aggregated and stored, allowing us to verify its origin and the process by which the data was transformed. This guarantees greater reliability for the platform as a whole.
- **External sources layer**: This layer represents external services, databases, historical bases, social networks, and any external data sources that can be used to add to the data collected by the streaming layer. From this layer, new sources can be used by the platform. By aggregating social networks, for example, it is possible to promote the platform's services in a targeted manner, considering possible new users and services related to some type of agricultural production.
- **Visualization layer**: This layer encompasses services and applications to assist in the integrated visualization of information and also in decision making. It is possible to analyze and interpret data at different time granularities. Furthermore, different services can be aggregated, with the use of dashboards and intelligent self-adaptive applications, which can generate, for example, alerts for the user about critical events such as possible outbreaks of a disease, or alerts about possible floods or even possible nutritional problems in animals, among others.

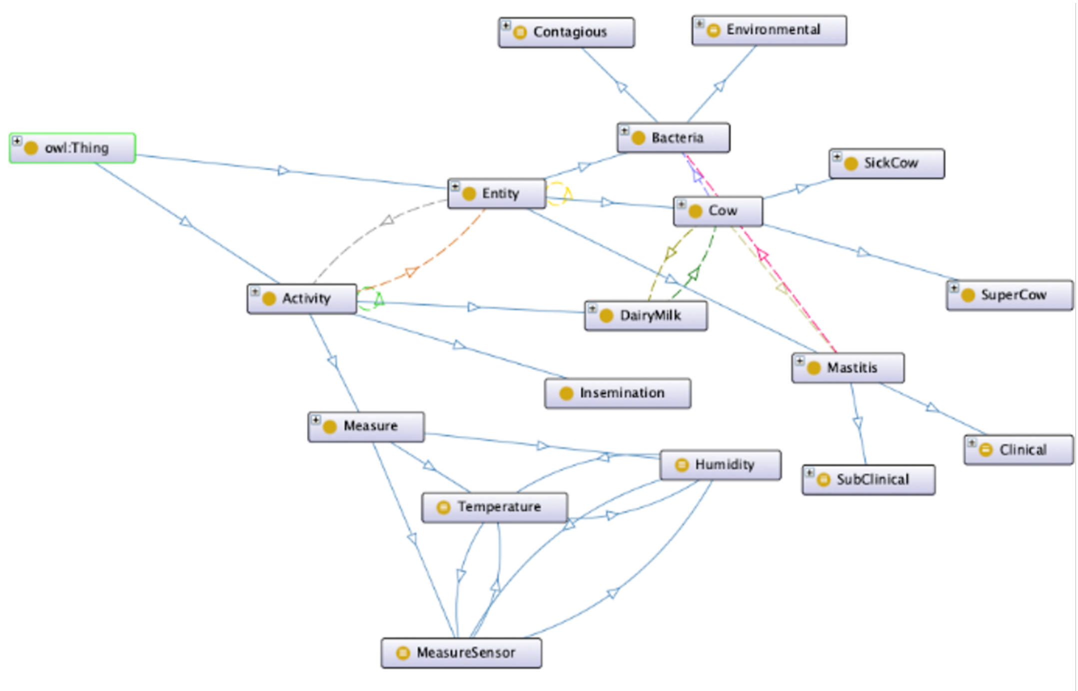

Figure 2: DairyCattleOntology main classes and associations.

4 A BRIEF EVALUATION

The SECO LIoT platform was developed and deployed to collect data, including weight and milk production in a Compost Barn environment. The dataset was organized by months and animals. Collected data underwent processing and instantiation within developed ontology with rules for inferring measures of temperature and humidity. External data from the INMET API was used to fill gaps in the sensor data. A dataset enriched by ontology processing was created for machine learning (ML) training. Various algorithms were tested, with Neural Network showing the best performance. Metadata for the trained models, including Mean Absolute Error (MAE) and Root Mean Square Error (RMSE), were recorded.

The reporting phase provided insights into different aspects of the Compost Barn environment. The system allowed producers to monitor the environment through a mobile application dashboard. It included variables like animal weight, milk production predictions, and food consumption per batch. The integration of ontology and ML enabled the system to infer relationships. For example, it identified sick cows, super cows, and mastitis cases.

The system then triggered automated actions related to environment adjustment. For instance, the system triggered actions such as turning on/off exhaust fans based on temperature and humidity conditions to maintain optimal conditions for animals. In addition, the system allowed for automated detection of mastitis cases and allowed for timely medication and prevention measures. ML algorithms predicted milk production accurately, aiding in production planning and decision-making.

The efficacy of the SECO LIoT platform was evident in its successful handling of compost barn data. Producers, armed with additional contextual information, notably climate forecasts, demonstrated the capacity to make informed adjustments to the barn's ambient temperature, thereby mitigating abrupt changes with potential repercussions for animal production. This underscores the platform's effectiveness in supporting decision-making by seamlessly integrating sensor data with contextual information, presented graphically alongside automated alerts. The collaborative exchange of information among the platform's various services and applications further contributed to the enhancement of the overall livestock business model.

5 CONCLUSION AND FUTURE WORK

In response to the intricate challenges inherent in decision-making within the Agriculture 4.0 landscape, this study introduces the LIoT architecture as a strategic intervention to bolster decision-making capabilities in precision livestock. Engineered for seamless data collection, processing, storage, and enrichment from sensors embedded in animals and their environments, the architecture underwent a comprehensive case study to evaluate its implementation viability in precision livestock contexts. The study findings not only affirm the feasibility of deploying the LIoT architecture to enhance decision-making but also shed light on its adeptness in navigating the complexities arising from diverse information sources and devices in agricultural settings.

Looking ahead, future work in this domain should delve into optimizing and refining the LIoT architecture, exploring novel avenues for its application in different livestock subdomains. Additionally, further research could focus on enhancing the architecture's capacity to support emerging technologies and evolving farm management practices. The study recognizes the untapped potential of Machine Learning (ML) techniques in optimizing IoT systems within precision livestock operations, indicating a promising direction for future investigations. Exploring advanced ML algorithms and refining their integration into the LIoT architecture could unlock even more profound insights for informed decision-making, laying the groundwork for continuous improvements in overall farm efficiency and sustainability.

Analogously to other branches of IoT that have emerged, such as Industrial IoT (IIoT) [14] and Internet of Medical Things (IoMT) [15], we believe that the software ecosystem architecture communicated here is the materialization of a potential novel avenue of interest in IoT: the Livestock IoT (LIoT). The main characteristics of LIoT are that (i) the devices are deployed in living animals (in our study, for instance, the animals use necklace devices), (ii) the deployment environment should cope with self-adaptive features [3] to assure the prescriptive health conditions for the animals and (iii) ML can be used to infer and predict the conditions in the environment, so that insights and knowledge can be obtained from the process at runtime. The technology stack, in general, can be preserved (when compared to other approaches), with differences more evidence in the data collecting edge, potentially arising novel challenges for the software engineering of that IoT branch, such the prioritization of quality attributes (QA) as sustainability and animal welfare, and all the concerns needed to make those QA satisfied

The study's relevance extends to global food production challenges, and future endeavors should expand its impact by conducting more case studies in diverse real-world farm contexts. To fortify the architecture's robustness, future research could delve into defining new semantic rules for data enrichment within the ontology, fostering better integration with domain-specific ontologies, and expanding the capacity for knowledge extraction. Furthermore, the study's emphasis on quality attributes such as flexibility, extensibility, and scalability provides a foundation for future work in refining these attributes and exploring additional dimensions crucial for a sustainable and adaptive architecture. Future research initiatives could also explore the introduction of novel intelligent models and algorithms into the LIoT ecosystem, continually pushing the boundaries of innovation in livestock management. By engaging in ongoing research, the LIoT architecture can evolve into a dynamic and responsive solution that not only meets current challenges but anticipates and adapts to the evolving landscape of precision agriculture.

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