Microservice architecture for a remote management platform for pastured poultry farming using Amazon Web Services and wireless mesh sensor networks

Arquitectura de microservicios para una plataforma de gestión remota para la cría de aves en pastoreo utilizando Amazon Web Services y redes inalámbricas de sensores de malla

Arquitetura de microsserviços para uma plataforma de gerenciamento remoto para avicultura a pasto usando Amazon Web Services e redes de sensores mesh sem fio

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Abstract

Introduction: Microservice architecture for a remote management platform for pastured poultry farming using Amazon Web Services and wireless mesh sensor networks, Universidad Tecnológica de Panamá, 2023.

Problem: Precision Livestock Farming (PLF) technologies assist the management of animal production industries, such as using Wireless Sensor Networks (WSN) in poultry farming. Current WSN-based systems for poultry farming lack robust but flexible software architectures to ensure the integrity and proper delivery of data.

Objective: To design a microservice-based software architecture (MSA) for a remote environmental management system based on Wireless Mesh Sensor Networks (WMSN) for pastured poultry.

Methodology: A review of MSAs for animal farming was conducted to synthesize the key factors considered in the design process of the system data flow, microservice definition, and environmental monitoring system technology selection.

Results: A cloud MSA with a multilayered scheme using the Amazon Web Services (AWS) platform was developed, validating the persistence of environmental data from WMSN prototype nodes to be deployed in mobile chicken coops.

Conclusion: Defining an End-to-End data flow facilitates the organization of tasks by domain, allowing efficient event communication between components and network reliability at both the hardware and software levels.

Originality: This study presents a novel design for a remote environmental monitoring system based on WMSN for mobile coops used in pastured poultry and a multilayered MSA cloud management platform for this industry.

Limitations: Software architecture technology selection was based only on services offered to the date of the study in the free tier of the Amazon Web Service platform.

Keywords: cloud computing, Internet of Things, microservices, poultry, remote management, wireless mesh sensor network.

Resumen

Introducción: arquitectura de microservicios para una plataforma de gestión remota para la avicultura en pastoreo utilizando Amazon Web Services y redes inalámbricas de sensores de malla, Universidad Tecnológica de Panamá, 2023.

Problema: las tecnologías de ganadería de precisión (PLF) ayudan a la gestión de las industrias de producción animal, como el uso de redes de sensores inalámbricos (WSN) en la cría de aves de corral. Los sistemas actuales basados en WSN para la cría de aves de corral carecen de arquitecturas de software sólidas pero flexibles para garantizar la integridad y la entrega adecuada de los datos.

Objetivo: diseñar una arquitectura de software basada en microservicios (MSA) para un sistema de gestión ambiental remota basado en Wireless Mesh Sensor Networks (WMSN) para aves en pastoreo.

Metodología: se realizó una revisión de MSA para la cría de animales para sintetizar los factores clave considerados en el proceso de diseño del flujo de datos del sistema, la definición de microservicios y la selección de tecnología del sistema de monitoreo ambiental.

Resultados: se desarrolló un MSA en la nube con esquema multicapa utilizando la plataforma Amazon Web Services (AWS), validando la persistencia de datos ambientales de nodos prototipo WMSN para ser desplegados en gallineros móviles.

Conclusión: definir un flujo de datos End-to-End facilita la organización de tareas por dominio, permitiendo una comunicación eficiente de eventos entre componentes y confiabilidad de la red tanto a nivel de hardware como de software.

Originalidad: este estudio presenta un diseño novedoso para un sistema de monitoreo ambiental remoto basado en WMSN para cooperativas móviles utilizadas en aves de pastoreo y una plataforma de administración en la nube MSA de varias capas para esta industria.

Limitaciones: la selección de tecnología de arquitectura de software se basó únicamente en los servicios ofrecidos a la fecha del estudio en el nivel gratuito de la plataforma Amazon Web Service.

Palabras clave: computación en la nube, Internet de las cosas, microservicios, avicultura, gestión remota, red inalámbrica de sensores de malla.

Resumo

Introdução: arquitetura de microsserviços para uma plataforma de gerenciamento remoto para aves de capoeira usando Amazon Web Services e redes de sensores de malha sem fio, Universidade Tecnológica do Panamá, 2023.

Problema: As tecnologias de Agricultura de Precisão (PLF) auxiliam o gerenciamento de indústrias de produção animal, como o uso de Redes de Sensores Sem Fio (WSN) na avicultura. Os atuais sistemas baseados em RSSF para avicultura carecem de arquiteturas de software robustas, mas flexíveis, para garantir a integridade dos dados e a entrega adequada.

Objetivo: projetar uma arquitetura de software baseada em microsserviços (MSA) para um sistema de gerenciamento ambiental remoto baseado em Redes de Sensores de Malha Sem Fio (WMSN) para aves em pastejo.

Metodologia: Uma revisão do MSA para Pecuária foi realizada para sintetizar os principais fatores considerados no processo de design do fluxo de dados do sistema, definição de microsserviços e seleção de tecnologia do sistema de monitoramento ambiental.

Resultados: um MSA em nuvem com um esquema multicamadas foi desenvolvido usando a plataforma Amazon Web Services (AWS), validando a persistência de dados ambientais de nós de protótipo WMSN para serem implantados em galinheiros móveis.

Conclusão: definir um fluxo de dados End-to-End facilita a organização de tarefas por domínio, permitindo uma comunicação eficiente de eventos entre componentes e confiabilidade da rede tanto no nível de hardware quanto no nível de software.

Originalidade: Este estudo apresenta um projeto inovador para um sistema de monitoramento ambiental remoto baseado em WMSN para cooperativas móveis usadas em pastejo de aves e uma plataforma de gerenciamento de nuvem MSA multicamada para esta indústria.

Limitações: A seleção da tecnologia de arquitetura de software foi baseada exclusivamente nos serviços oferecidos na data do estudo na camada gratuita da plataforma Amazon Web Service.

Palavras-chave: computação em nuvem, Internet das coisas, microsserviços, avicultura, gerenciamento remoto, rede de sensores mesh sem fio.

1. INTRODUCTION

The consumption of animal-based food products presents a growing demand in different latitudes of the world, therefore, livestock production industries, both on a small and large scale, play a fundamental role to be considered during the process of defining targeted strategies to improve the mechanisms required for strengthening factors like food security, socioeconomic development, as well as poverty and hunger reduction in different countries of the world [1]. Along these lines, despite their limited resources, small producers play an important role in ensuring adequate food supply in different regions of each country, as stated in Goal 2: Zero Hunger of the Sustainable Development Goals (SDG) within the 2030 Agenda of the United Nations (UN) [2]. It is imperative to generate new tools and technologies that help these producers maximize the performance of their businesses while maintaining competitiveness and on-time responses to consumers' needs.

Smart Agriculture (also called Agriculture 4.0) is one of the main research domains in Internet of Things (IoT) technologies, in which the design, development, and implementation of new hardware and software solutions is procured to establish communication between electronic devices and digital platforms, with the goal of collecting all relevant information for production activities, efficiently managing process execution and resources, and consequently, facilitating the generation of reports and statistical projections that could help producers and industry-related stakeholders in the decision-making process. In other words, Agriculture 4.0 is a concept that involves a set of strategies for taking advantage of IoT technologies to optimize the management and execution of activities required in various stages of food production-related industries, having the ability to continuously monitor the status of the production, as well as improve the use of time and available resources, aiming to develop a truly intelligent agriculture, capable of satisfying the crescent market and public demands [3]. In this context, the poultry production industry stands out as one of the main beneficiaries of this type of technology development strategy, especially in easing supervision activities in extensive production systems, such as: free-range and pastured poultry farming where birds are raised in open fields [4], considering the economic importance that poultry products have for developing countries, as well as the lofty standards that the public expects from this industry to ensure the proper rearing and welfare conditions of commercialized birds [5].

However, the current adoption rate of these new technologies is hampered by key factors such as high entry cost of implementation, lack of awareness by producers about the benefits provided in the long term by these solutions for their business, and available systems being developed under closed communication standards that prevent integration and interoperability between devices and systems from different manufacturers. Nevertheless, IoT technologies for precision livestock farming (PLF) offer a wide range of solutions specifically tailored for poultry production, including computer vision systems used for automated counting of birds, electronic tags for movement detection, sound analysis for health monitoring, and environmental sensors for rearing supervision [6]. In this sense, the deployment of WSNs facilitates constant monitoring of food production industries, even in rural areas without the need for human intervention [7], making efficient use of limited storage capacity, battery life, and energy consumption, as well as the transmission range of the devices [8], which requires the design of specialized algorithms capable of supporting the transmission of the type of data managed by these solutions [9].

The development of software architectures for remote monitoring with WSNs has led to the implementation of distributed information management systems, which respond to the design of microservice-based software architecture (MSA) tailored to facilitate the integration of different types of technologies and allow interoperability between a wide variety of commercial solutions. Although different implementations have been observed in the development of these types of solutions in food production, the deployment of WSN-based systems in contexts such as poultry farming still requires the design of a robust software architecture that takes into account specific features for the requirements of the type of animal management; one which also ensures the integrity of the data transmitted in the different stages of the information life cycle [10], and simultaneously provides sufficient flexibility for possible network expansions and/or reorganization of the deployed components as the business so requires, as has been found in studies reporting the deployment of MSA management systems in different animal production industries such as beekeeping [11] and cattle farming [12]. The development of MSA management systems involves the use of design patterns that deconstruct the composition of systems into various components known work as microservices, each dedicated to a specific functionality or required feature [13]. In this way, systems are made up of multiple components of lesser complexity and with low interdependence among themselves, which allows for their modification and maintenance without completely affecting the global operation of the system, while speeding up the response capacity to new business requirements and goals as they arise [14].

Given the important role played by the livestock industry in terms of ensuring food security in our countries, and the growing development of MSA information systems designed for the integration of PLF monitoring solutions like WSN in rearing spaces, it is pertinent to carry out a study that proffers knowledge of the state of the art in terms of scientific research on the development of this type of tool, aimed at supporting animal production activities, and summarize the key factors that must be taken into consideration for the development of remote management systems for the poultry industry. This article presents an MSA for the development of a remote monitoring system for environmental conditions in pastured poultry farming using WSN, mobile technologies, and cloud computing. This study aimed to answer the main research question: *What characteristics should microservice-based software architectures have for the development of environmental management systems in poultry production spaces*?

The remainder of this paper is organized as follows: Section 2 - Literature review presenting the state of the art regarding the development of MSAs in different animal production industries; Section 3 - Materials and methods describing the overall components of the remote management system and the design of the MSA; Section 4 - Results presenting the implementation of the MSA, an analysis of the cloud technologies involved, and factors considered during the development and testing process; Section 5 - Discussion presenting the analysis of the answers obtained for the research question; and Section 6 - Conclusion including the main observations acquired from the study and discussions regarding future works.

2. LITERATURE REVIEW

This section presents a review of state-of-the-art studies reporting the design of MSA for the development of cloud monitoring platforms. The scope of the review focused on empirically supported technological solutions for the remote management of animal production activities and parameters. The descriptions of the main findings and implementations reported by the authors of the analyzed studies are as follows:

In [15], the authors presented the development of a web and mobile platform for the remote monitoring of animal welfare conditions of farms dedicated to cattle and pig rearing, as well as poultry farming. The system integrates readings of different parameters captured through wireless devices located in the body of the livestock and in their rearing spaces, with the captured information managed on a web platform through microservices dedicated to the storage and presentation of data. This type of architecture has also been applied to the supervision of pig feed silos using wireless laser measurement devices and microservices for system user authentication and alerts, as reported in [16].

In the context of cattle farming, studies [12] and [17] described the development of two platforms for the remote monitoring of animals raised in the field. These platforms consist of specialized microservices for animal health monitoring through wireless devices located on the hoof and/or neck of a cow, accompanied by machine learning models for the classification of movement patterns and behaviors for the early detection of diseases. Similarly, [18] presented an agile approach for the development of this type of platform, reporting the design of a scalable MSA for data management and event communication between components using cloud computing technologies offered by the Amazon Web Services (AWS) platform.

Similarly, the authors of [19] reported the design of a platform for data acquisition, storage, and digitization of companies dedicated to aquaculture. This study presents the development of wireless environmental sensors to monitor water tanks dedicated to fish production and transmit captured data to a web dashboard with services for data analysis. Similarly, a study [20] described the design of a reactive MSA to communicate the components of an environmental monitoring system based on a self-organizing WSN for aquaculture production. In addition, [21] reported the design of a system for the early detection of pathogenic bacteria in seafood using biosensors, and MSA for the management of captured parameters through a processing strategy based on state machines.

In the beekeeping industry, a study [11] described an online platform for the remote monitoring of environmental conditions in beehives for commercial honey production. This platform uses a microservice to communicate wireless sensor readings from beehives to the end user's monitoring application. In addition, a study [22] presented an MSA for processing, modeling, and integrating heterogeneous data obtained from wireless devices installed for real-time monitoring of beehives for commercial honey production.

3. MATERIALS AND METHODS

This study presents the design and development of a platform for remote environmental monitoring of pastured poultry farming rearing spaces, such as chicken tractors or mobile chicken coops, using WSN nodes deployed as a mesh, also known work as a WMSN. WMSN technologies allow the use of secure communication protocols for robust scalable deployments and efficient energy consumption, without the need to combine different network technologies [23], which have been tested in scenarios such as office monitoring [24], home automation [25], factory management [26], and even robot communication [27]. Figure 1 shows the design of the overall network architecture of the system and the relationships between the components.

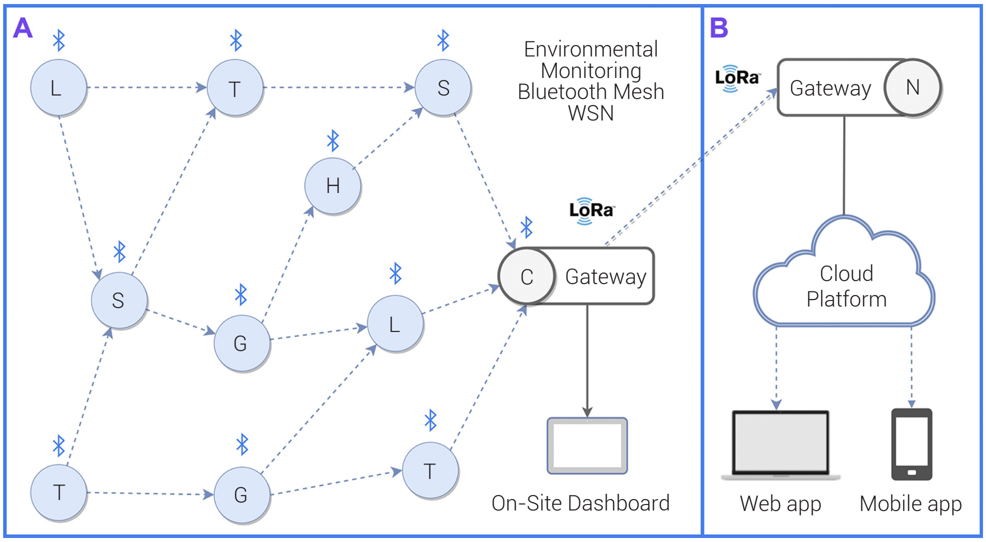

Figure 1. Overall architecture of the environmental monitoring system.
Source: own work.

From left to right, Section A in the diagram corresponds to the deployment of the WMSN in the poultry rearing space based on a mid-to large-sized mobile chicken tractor [28], to monitor the status of different environmental parameters on the inside. Each node of the network is labeled with a letter specific to the type of sensor for supervised parameters, such as lighting (L), temperature (T), sound (S), relative humidity (H), and air quality (G). These nodes are arranged in a mesh topology, in which each node can take advantage of its proximity to other neighboring nodes to use them as a relay so that the information generated can be successfully transmitted to the sink node (C). The use of computing devices at the edge of the network helps reduce the information processing load that would otherwise fall on devices in the fog or cloud, speeding up the analysis of information and reducing the size of data packets transmitted by each node [29].

The sink node (C) is responsible for collecting and processing the data received by the network nodes and presents the environmental condition readings locally through an administration panel on an integrated screen. Simultaneously, this node acts as an IoT gateway to node (N) for transmission of the data generated in the rearing space over long distances. Subsequently, node (N), presented in Section B, functions as a network gateway to the Internet, communicating the received data to a cloud platform for further storage, processing, analysis, and remote management through web browsers or a mobile application.

3.1. Overview of the proposed system data flow

Successful execution of Agriculture 4.0 strategies for industry digitalization in food production requires the development of new technologies that fulfill business objectives [30] by providing useful insights to support decision-making activities in each production stage [31]. End-to-end analytics allows the effective modeling of system information distribution through its different processing stages, from data source devices to the final interaction channels used by end users, which can be represented using a data flow diagram [32]. Figure 2 presents a general view of the end-to-end data life flow of the system, taking into consideration the information processing stages from data capture origin devices, followed by local data processing stations, and arriving at the final presentation for end users' devices. The system data flow diagram comprises three integrated levels, as described below.

1. The **upper level** represents the different computing elements that make up the environmental monitoring system, starting with sensor nodes at the edge of the network, continuing with a hub station for the execution of fog computing mechanisms, such as on-site processing and temporary data persistence, and ending with an Internet cloud computing platform for user-friendly remote information access, long-term data analytics, and system management.
2. The **intermediate level** presents the definition of seven sequential stages of the life flow of the data in the complete system, ranging from the initial capture of the data corresponding to the measurements of the physical environmental parameters, to the final presentation of the information for the corresponding interpretation by end users.
3. The **lower level** corresponds to a breakdown work of the main tasks involved in fulfilling the stages of data flow and the specific treatment, to which the information must be subjected, to meet the functionality of the proposed system in line with the requirements established by the business objectives.

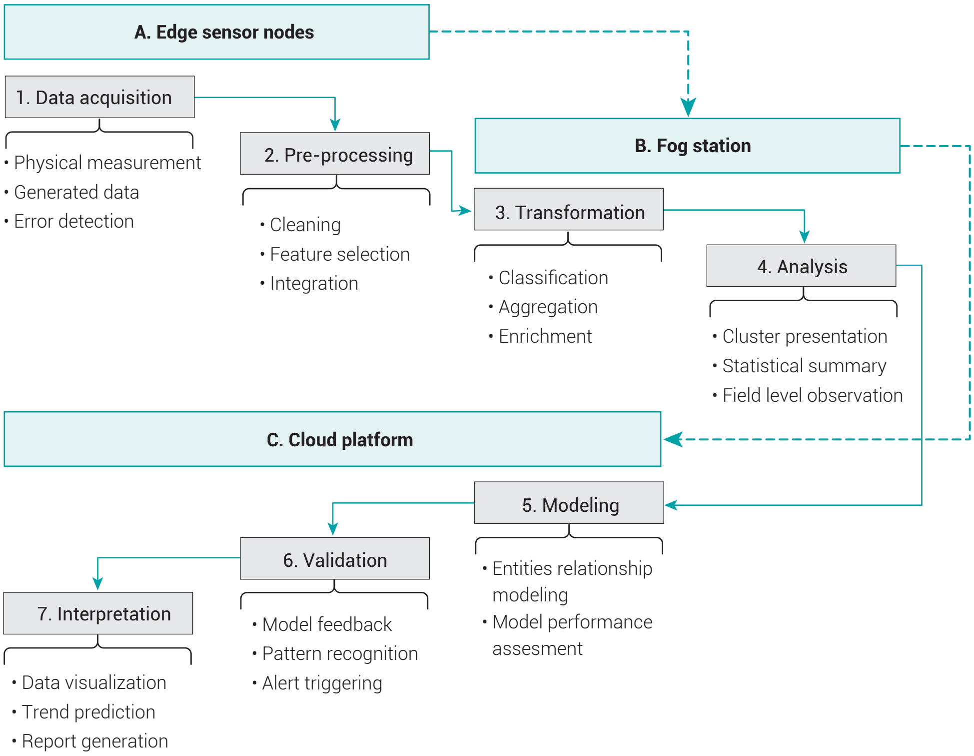

Figure 2. System data flow diagram.
Source: own work.

3.2. Layered microservice architecture description

For this research, the design of a multilayer MSA inspired by the proposals presented in [12] and [20] was chosen for the development of the cloud platform for the system. In this sense, a multilayered MSA allows the organization of system components around business requirements, facilitating aspects such as agile development, testing, feature deployment, and data automation [33], while providing compatibility with the scalability, elasticity, and rapid provisioning of resources through the implementation of cloud computing technologies [34]. Figure 3 shows the design of the multilayered MSA for the remote-monitoring cloud platform.

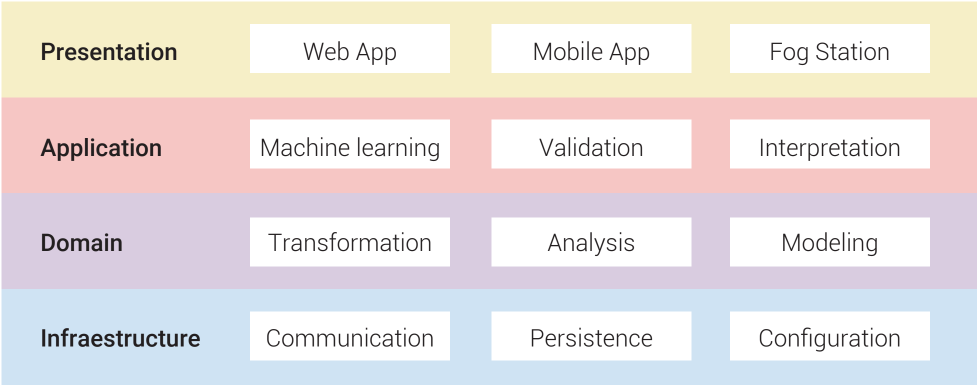

Figure 3. Multilayered microservice architecture for the system.
Source: own work.

The design is based on a hierarchy of four domain layers to define the communication scheme between microservices, as well as for the categorization of different system functionalities, stacked from top to bottom as follows: Presentation layer, Application layer, Domain layer, and Infrastructure layer. Each domain layer is composed of a variety of microservices to accomplish the main tasks defined in the Transformation, Analysis, Modeling, Validation, and Interpretation stages presented in the system data flow diagram in Figure 2, as well as a number of complementary tasks to support the system configuration, maintenance, and execution. The four domain layers' responsibilities and their required microservice implementations are described as follows:

- The **Presentation layer** includes procedures for data delivery and final information visualization by end users.
    - **Web App microservice**: is made up of specialized tasks for displaying information through web browsers.
    - **Mobile App microservice**: is composed of tasks designed to communicate information through smartphones or tablets.
    - **Fog station microservice**: is designed with specific tasks to display synthesized information on local devices in the field.
- The **Application layer** oversees tasks for data treatment and business logic execution.
    - **Machine Learning (ML) microservice**: is composed of tasks for pattern detection and predictions generation based on historical data.
    - **Validation microservice**: comprises tasks dedicated to validating the quality of the data captured by the components of the system.

  - **Interpretation microservice**: a set of tasks dedicated to the use of different inferences to report the current system situation.
- The **Domain layer** is responsible for modeling and correctly representing business logic and data in the system.
  - **Transformation microservice**: a group of tasks dedicated to processing raw data into the appropriate formats used by the system.
  - **Analysis microservice**: is composed of specific tasks for the generation of information resulting from the processing of captured data.
  - **Modeling microservice**: tasks oriented to the digital representation of the relationship between business entities.
- The **infrastructure layer** is responsible for the persistence and communication of data, as well as the configuration between the components.
  - **Communication microservice**: tasks for managing communication between the internal and external components of the system.
  - **Persistence microservice**: is made up of specific tasks dedicated to data management and information backup.
  - **Configuration microservice**: a set of tasks responsible for executing the necessary configurations for system integration.

4. RESULTS

Real-world validation of the proposed system involved the development and testing of preliminary prototypes of the WMSN nodes that enabled the communication of data from the mobile chicken coop in the field to the cloud-based remote monitoring platform, as well as the implementation of cloud computing technologies for the development of the MSA.

4.1. Environmental data transmission

The testing process began by considering how the environmental data would be captured and the format in which this information would be structured for processing and transmission according to the data life flow stages. In this case, the dataset provided in [35] was used to represent the environmental information captured by the nodes of the WMSN deployed inside the mobile chicken coop. This dataset was composed of environmental data captured from three wireless monitoring stations in a multiple-sensor array configuration. The environmental information is structured in comma-separated values (CSV) format in which each row contains data corresponding to the measurement of each of the following parameters: date and time of capture, source device, carbon monoxide (CO), relative humidity (%RH), presence of light, liquid petroleum gas, motion detection, smoke presence, and ambient temperature. This dataset was used given the similarity of the included parameters with those to be captured independently by each of the WMSN nodes, as well as for the final information structure format compatible with the data aggregation strategy proposed for the implementation of the fog station in this study.

4.2. WMSN Gateway nodes prototypes

For the initial test process of the wireless environmental monitoring network, prototypes of fog station nodes C and N presented in Figure 1 were developed, which correspond to the WMSN gateways. Figure 4 shows the hardware components used for the initial prototyping and testing of gateway nodes. Node C is composed of a Raspberry Pi 3b+ microcomputer as the central fog computing device for the execution of the tasks described in Stages 3 and 4 in the data flow diagram presented in Figure 2. The environmental information to be transmitted was stored locally in the device in CSV format, using a Python script to read each row sequentially and send the readings via serial communication to the Heltec WiFi Lora 32 (V2) microcontroller, where the data are transmitted over a long distance to node N using LoRa communication technology. In turn, gateway node N is composed only of a Heltec WiFi Lora 32 (V2) microcontroller, which needs to be connected to a local Internet network over Wi-Fi communication to be able to send the data received via LoRa transmission from node C to the remote monitoring platform in the cloud.

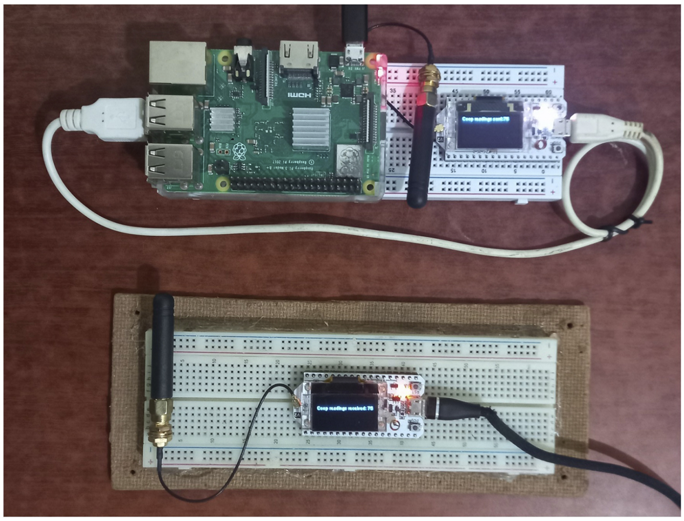

Figure 4. Gateway nodes prototypes for the remote environmental monitoring system.
Source: own work.

4.3. Cloud platform technology selected

Figure 5 presents a cloud platform architecture diagram for the remote monitoring system based on the implementation of resources provided by Amazon Web Services (AWS) [36], as this platform offers an ecosystem of highly configurable and reliable services applicable to animal farming, as shown work in [18]. With the intention of testing and validating the performance of the basic microservice functionalities involved in the reception of environmental data in the cloud platform according to the designed MSA, the technology selection for the proposed cloud architecture was limited to services available in the free tier offered in the AWS cloud catalog at the date of the study. For microservice development, the process was conducted using the tools included in the Spring Boot framework, based on the Java programming language, particularly the libraries designed for the development of web applications and the software development kit (SDK) necessary for the applications to interact with AWS DynamoDB NoSQL databases.

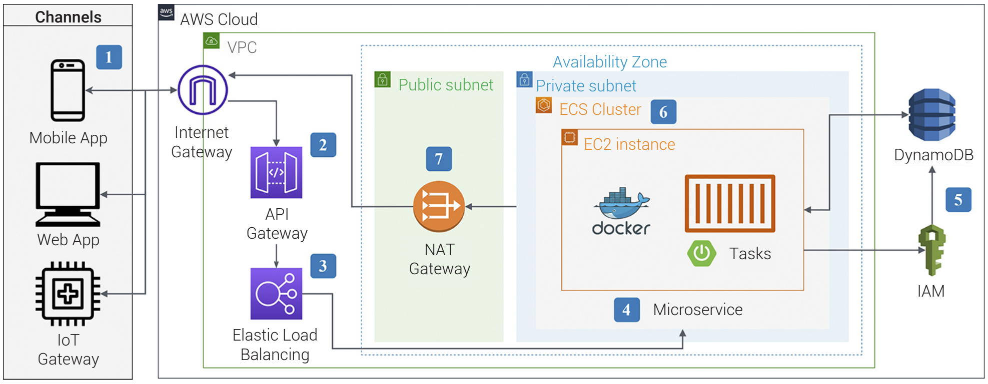

Figure 5. Cloud platform technologies architecture diagram.
Source: own work.

The relationships between the different technologies selected are described as follows:

1. First, the cloud platform can receive different calls by sending or requesting information through different communication channels, such as a mobile application, web application, and/or from the IoT gateway.
2. These calls are made using the API Gateway service, which provides definition access for different functional components and data in the platform as requested. These components are provisioned inside a private subnet configured using the Virtual Private Networks (VPC) service of the AWS cloud.

3. After receiving the calls via the API Gateway, these requests are forwarded to the Elastic Load Balancing (ELB) service, which acts as a network load balancer to distribute the requests between the required Elastic Cloud Computing (EC2) service-computing instances necessary for each functionality of the platform.
4. These functionalities are designed as microservices that are independently isolated in EC2 instances using Docker containers. Each microservice has a set of specific tasks and methods programmed in a Spring Boot application.
5. Each microservice instance is assigned a set of Identity and Access Management (IAM) credentials to access the DynamoDB NoSQL database service configured for data persistence.
6. Management of the EC2 microservices cluster requires the use of an Elastic Container Service (ECS) to oversee the orchestration of containers for scheduled microservice execution lifetime and performance monitoring.
7. Request responses are sent to the public subnet via a Network Address Translation (NAT) Gateway service acting as a bridge to the Internet Gateway of the AWS Cloud to allow outbound traffic to reach the corresponding requesting devices.

4.4. Persistence microservice deployment

The first development and testing cycle of the designed MSA focused on validating the execution of the tasks defined for the operation of the persistence microservice presented in the infrastructure domain layer. This microservice was programmed as a single Spring Boot application using a Model-View-Controller (MVC) software design pattern to define the methods required to send and request environmental data with the database. Figure 6 shows the table structure designed for the reception of environmental data items.

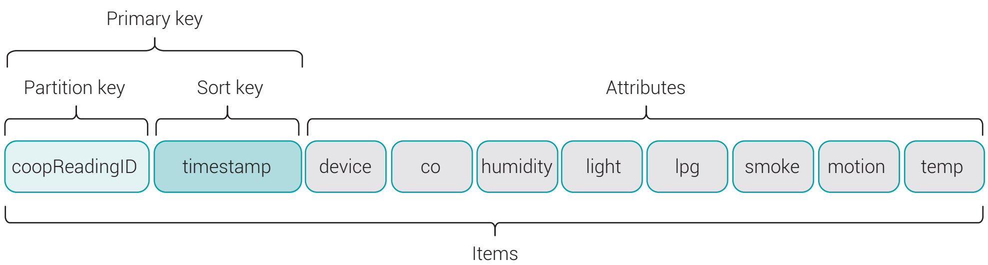

Figure 6. DynamoDB table diagram.
Source: Own work.

Key fields taken into consideration are the Partition key, which acts as the unique identifier of each row, and the Sort key that allows fast filtering and organization of information; together, these fields compose the Primary key of the table registries. The remaining fields in the Attributes section correspond to the environmental data to be stored. Although the table diagram shows all table items together, this does not always need to be the case, given the data modeling flexibility of non-relational databases. The only mandatory field to save a new registry in this case is the Partition key (and the Sort key in case of a composite Foreign key), and the remaining items can be stored independently or in different orders depending on the defined data transmission strategy. Figure 7 shows a screenshot of the DynamoDB table in the AWS console of this project with a list of rows of environmental data stored using the persistence microservice and a data aggregation strategy.

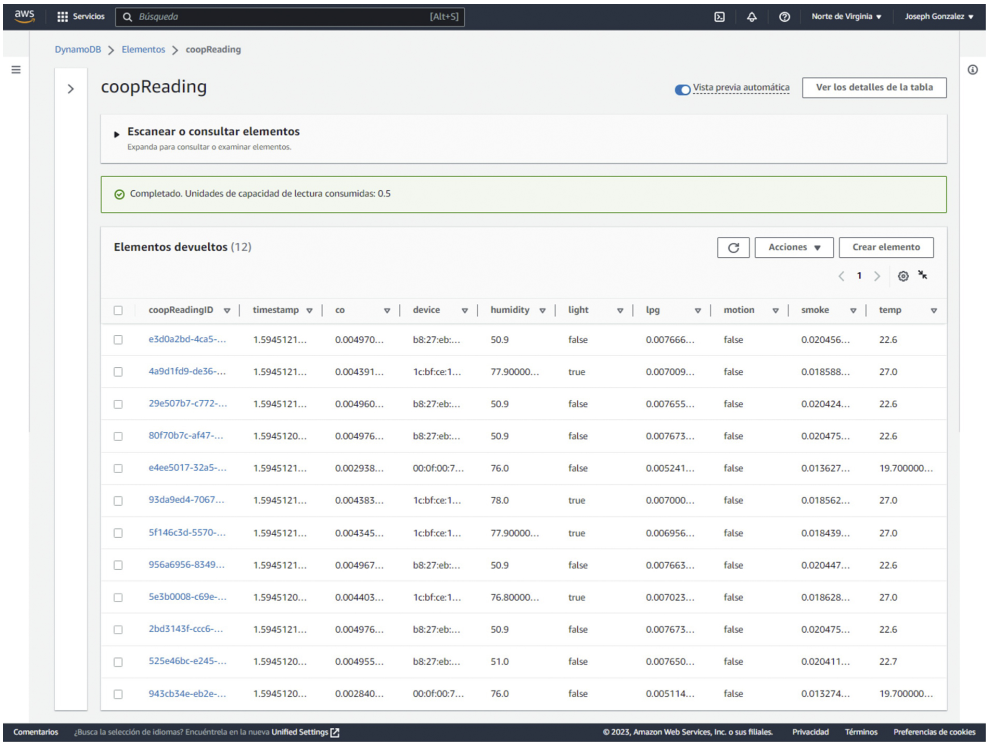

Figure 7. The environmental data were stored in the DynamoDB database.
Source: own work.

5. DISCUSSION

Among the main contributions of this study, a survey of the state of the art regarding the development of remote management systems in animal production industries was conducted to answer the following research question: **What characteristics should microservice-based software architectures have for the development of environmental management systems in poultry production spaces?** The main results found in the literature, as well as their consideration and inclusion in the execution of this study, are described below.

- *End-to-End scope*

The system design process should start from a comprehensive vision of the desired solution, avoiding any restricting focus on specific stages of the process that could prevent adequate integration of internal and external components [12], easing the support of different types of data sources that could serve as input for the system in the future [22], while considering key usability factors such as reliable information distribution channels, user-friendly interfaces for the diversity of end devices, adaptive responses to network speed availability, precise insights for decision-making support, and more [11]. This type of comprehensive vision was included in the design of the data flow presented in Figure *2* to clearly define each stage of the overall performance of the remote management system.

- *Ease of customization on demand*

Systems developed to address current business demands should have a flexible and agile design to adapt to the ongoing request for new features as well as changes to existing service functionalities [22]. This requires the deployment of an adaptative software architecture design strategy that enables the isolation of different system modules, facilitating the distribution of updates to specific features without affecting the performance of other modules [16], and at the same time, ensuring that different systems' components can dynamically interact with each other to generate the results expected by end users [20]. This led to the definition of the layered MSA with 4 domains, presented in Figure *3*, to provide a framework that would allow the delimitation of the system domains, grouping of features, and integration of new services in line with business requirements.

- *Resource management and optimization*

The software architecture design process must implement the adequate strategies and tools required to reinforce the security controls over the entire system data flow [17], which includes computational stages such as on-site processing and cloud computing solutions, end-user applications, and data transmission protocols [15]. Subsequently, MSA design must rely on the implementation of proven mechanisms and reliable infrastructure to respond to the number of requests received by the system, preventing business performance from being affected by low response times [18]. This was considered during the technology selection stage for the MSA designed, as presented in Figure 5, taking advantage of consumer-grade cloud computing tools currently available in the market.

6. CONCLUSIONS

Reports in the scientific literature on the design of MSA for the development of remote management platforms for animal farming have grown work in recent years. However, only a fraction of these solutions have focused on poultry production and the requirements of this specific industry, for which it has been considered important to delve into the development of technological solutions tailored towards this productive sector. This study presented the design of a multilayered MSA of a cloud platform, for a remote environmental monitoring system, for pastured poultry farming, through the implementation of wireless sensor networks, distributed in a mesh topology, in rearing spaces such as mobile chicken coops.

The designed microservice-based software architecture oversees the overall remote monitoring system data flow, from the capture stage of physical parameters through different measurement devices, to the presentation of information to end users on their preferred devices. A multilayered architecture design based on four domain layers was selected for the organization of the system functionalities, which are represented as microservices specific to the core business requirements. The fundamental performance of the system was evaluated through the implementation of technologies provided by the AWS cloud as well as communication between the system components through the Internet.

In future work, we will proceed with the development of physical devices for wireless mesh sensor networks, the development of new features for the remote monitoring cloud platform in line with the business requirements of poultry farming, and the development of a multiplatform application so that end users can easily access the system information.

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