System Architecture Based on The Internet of Things and Cloud Computing which Assist Cows Heat Detection

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Abstract

The traditional heat event detection method is widely employed to detect estrus activity in dairy farms where the number of cows is not high; however, this method demands high expertise and requires large periods of external observation, which hinders breeding administration and remote monitoring. To reduce dairyman expertise dependency and enable remote monitoring is necessary to systematize the heat events detection method. This paper presents a system architecture based on the Internet of things and cloud computing which aims to support the process systematization of the traditional heat event detection method reducing dairyman expertise and external observation dependency. This system architecture implements cloud services provided by amazon web services and allows the final user to monitor the heat events through a web application and mobile application. The system architecture proposed will be validated through content validation by panel of experts.

***Keywords— Estrus, cows heat detection, cloud computing, Internet of things*.**

I. INTRODUCTION

Nowadays, the information systems dedicated to monitoring the cattle in dairy farms in which the numbers of dairy cows are not so high are a little bit used since all works related to monitoring and to detect heat events are performed through traditional observation.

Heat or estrus is the event when cows signal that they are receptive to be mated and unique behaviors associated with heat may last from six to thirty hours [1].

According with Li and Wang [2] traditional dairy cow cultivation decides the status of dairy cows based on manually observation on the amount of activity, excitement, mounting, mounted, lying time, and body temperature detection of the dairy cows, which are not accurate enough.

The time of standing heat varies between cows and vary from approximately [6] to 24 hours, with an average period of 16 hours [3], additionally, most of the heat event occurs at night or at the beginning of the morning, whereby almost 70% of the mounting activity performed between 7:00 p.m. and 7 a.m. [4], so that, if cow starts her heat event in the first hour of night in the next morning any estrous sign will appear, this increase the difficulty to monitor the heat event.

Effective detection of heat events has high importance in reducing the time when the cow is dry and helps to plan effective artificial insemination or detect the optimum time when the cow must be mated, then, inadequate estrus detection leads to mistimed breeding and reduces conception rates in cows, causing substantial losses from extended gaps between pregnancies [3].

Automated methods of heat event detection based on walking activity can be useful to reduce the dairyman expertise and the manual observation, however, is necessary implements specialized Hardware, causing increase in the implementation cost.

In this paper, it is proposed a system architecture that monitors the walking activity and the cow laying time to detect heat events. This system architecture implements cloud computing to reduce the specialized Hardware implementation cost, increasing the possibility to use it in different dairy farms; furthermore, the system architecture implements mobile and web application, and Internet of Things (IoT) devices which implements long-range (LoRa) communication. This allows us to increase the system accessibility

II. PROBLEMATIC

The traditional heat event detection method is used in most dairy farms in which the number of cows is not so high. This method has some limitations since it depends on dairyman's expertise, frequency of observation, and manual monitoring [5]. If the dairyman does not have enough expertise could not distinguish the cows' conduct properly and cause a misjudgment. In addition, most of the heat events occur at nigh reducing the accurate detection and increasing the difficulty of manual monitoring.

The traditional method limitation hinders the owner admin the pregnancy, delivery, and cows monitoring causing losses in their revenues [6] [5]. To reduce the dairyman's expertise dependency and increase the possibility of remote monitoring is necessary to have a systematized process, nevertheless, some technologies implement dedicated Hardware to process the sensors information, increasing the cost implementation.

III. BACKGROUND

A. *Heat (estrus) in Dairy Cows*

"Heat," or estrus, is the period that occurs, on average, every three weeks (18–24 days) in sexually mature, non-pregnant female cattle, when they are receptive to mounting or riding actively by a bull or other cows [1].

The main sign which indicates the heat is when the cow allows other herd mates to mount while she remains standing [14]. Additionally, there are secondary signs that include higher activities rate [1] roughened tail-head; dirty streaks and marks on lower hips, sides, or shoulders; grouping together; swollen vulva; a bloody discharge at the end of estrus usually indicates a missed heat [14].

Heat detection requires accurate observation of physiological behavior patterns and parameters [15] and could be made by traditional methods and automated methods. The traditional method is performed by visual observation of the dairy herd, rectal examination, tail marking, and so on [16] this method requires diligent attention and is time-consuming. The detection rate of the traditional method depends on the observation frequency and the time implemented in the observation [1] and its efficiency vary from 45% to 91% [17].

Automated methods include pressure sensors for detecting mounting activity, pedometers sensor for walking and activity monitoring for cows [15]. The detection rate using walking activity in automated methods vary from 70% to 80% [17].

B. Internet of Things

According to Gubbi *et al.* [18] Internet of thigs (IoT) is the interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless ubiquitous sensing, data analytics and information representation with cloud computing as the unifying framework. Probably the first person to say "Internet of things" was Kevin Ashton in a presentation made at Procter & Gamble (P&G) in 1999 [19].

According to Serparnos and Wolf [20] an IoT system may consist primarily of sensors; in some cases, it may include a significant number of actuators. In both cases, the goal is to process signals and time-series data. Some sensors available for IoT application are integrated accelerometers, gyroscopes, and chemicals sensors. The low cost and power consumption of these sensors enables new applications well beyond those of traditional laboratory or industrial measurement equipment [20].

IoT allow a lot of applications in different areas: home and building automation, smart cities, Industry 4.0, and smart agriculture [21].

Home and building automation use sensors to identify the locations of people as well as the state of the building. That data can be used to control heating/ventilation/air conditioning systems and lighting systems to reduce operating costs. Smart buildings and structures also use sensors to monitor structural health [20].

IoT in smart cities and urban areas collecting data on the city status and disseminating them to citizens [21].

The use of IoT in industrial systems use sensors for collect data, monitor the industrial process, the quality of the process and the state of the equipment [20].

Smart farming use new technologies to collect data and manage the data. IoT in smart farming aim at supporting farmers in their decision processes through decision-support systems [14].

C. Cloud Computing

According with Vaquero *et al.* [22] cloud is a large pool of easily usable and accessible virtualized resources (such as Hardware, development platforms and/or services). These resources can be dynamically re-configured to adjust to a variable load (scale), allowing also for an optimum resource utilization. This pool of resources is typically exploited by a pay-per-use model in which guarantees are offered by the infrastructure provider by means of customized service level agreements.

Amazon Web service (AWS) [23] describe cloud computing as on-demand delivery of information technology resources over the Internet with pay-as-you-go pricing. Instead of buying, owning, and maintaining physical data centers and servers, the technology services are accessed, such as computing power, storage, and databases, on an as-needed basis from a cloud provider.

The services provided by cloud computing are mainly based in three models: infrastructure as a service, platform as a service and Software as a service.

Infrastructure as a service provides processing, storage, networks, and other computing resources, allowing the consumer to deploy and run arbitrary Software, including OSs and applications [21].

Platform as a service provides the Software platform where systems run on. The sizing of the Hardware resources demanded by the execution of the services is made in a transparent manner [22].

Software as a Service provides the capability to use the provider's applications, running on the cloud infrastructure. These applications are accessed from client devices through suitable client interfaces [21].

D. Related Work

There exists in the literature proposed systems that implements cloud computing and IoT technologies in different application.

Jimbo et al. [7] in their paper "Agricultural product monitoring system supported by cloud computing" establish a more perfect modern agricultural IoT monitoring system, through the modern agricultural demand analysis, and study of IoT, cloud computing, big data and other related technologies, so it has a certain industrial application value. The data access, data persistence, data processing and business support service are based on Amazon AWS cloud service platform.

Dongxu et al. [8] presents in their paper "Architecture Design of Power System Fault Calculation Based on Cloud Computing Technology" an architecture of power system fault calculation based on cloud computing technology to solve the problems of the current fault calculation system, which is caused by the insufficient calculation ability. The proposed system is deployed in the Ali cloud computing platform considering security, fluency, stability, cost and ensuring the reliable and stable operation.

Plathong and Surakratanasakul [9] present a conceptual framework of integration IoT with Health Level 7 protocol for real-time healthcare monitoring by using Cloud computing, this framework was divided into five functional sections: IoT devices, application for support IoT device, Cloud computing, Web service and end user. This framework reduces the travel expenses and can be used anywhere anytime.

Srinivasulu et al. [10] propose a cloud service-oriented architecture for the agriculture. This architecture includes various services for the farming and farmers to such as farming monitoring, market oriented service, warehousing information, fostering agri-business development service, farmers training on usage of the information services, etc. which will minimize the expenditure for farming, minimizes the labor, saves the time and improves the crop yielding, provides the marketing information, banking and finance information, exchange of information among the farmers, scientists advises regarding the pest control, suitability of crop for a particular soil.

Taneja et al. [11] present a fog computing assisted application system for animal behavior analysis and health monitoring in a dairy farming scenario. The sensed data from sensors is sent to a fog-based platform for data classification and analysis, which includes decision making capabilities. The solution aims towards keeping track of the animal's well-being by delivering early warning alerts generated through behavioral analytics. Fog computing reduce the dependency in the cloud, improves the responsiveness of the system and reduces resource requirements on the remote cloud infrastructure, however, increase the infrastructure needed in the edge and increase the implementation cost.

Bellini and Arnaud [12] present a collar or an ear tag which includes an accelerometer and LoRa wireless connectivity, connected to a LoRa gateway. LoRa gateway sends the information to a server where data is processed and analyzed. This solution allows to collect the cows' activity and process and analyze the information in a server; however, it does not include information access interface for the final user and implements a dedicated server to process the information.

Burriuso et al [13] presents low-cost wireless network sensor (WSN) interconnected through a multi-agent architecture based on virtual organizations. This system offers remote farm monitoring and traceability service. The aim pursued in this work is to save the farmer from unnecessary movement from place to place and to increase the productivity of the farm, reduce costs and risky situations. The infrastructure of WSNs is capable of distributing communications in dynamic environments, increasing mobility and efficiency, regardless of the location. Nevertheless, this system requires dedicated Hardware to process the information that cause increase of implementation cost.

IV. PROPOSED SOLUTION

The objective of this research is to establish an architecture of a low-cost and high accessibility system that supports a systematized process and facilitated the cows' heat detection. This architecture implements cloud computing services provided by AWS and IoT devices.

A. SYSTEM REQUIREMENTS

It was considered five input drivers as system requirements to specify functional requirements and non-functional requirements: design purpose, primary functional requirements, quality attribute scenarios, constraints, and design concerns.

Design Purpose

The system architecture allows detecting cows' heat events through monitoring cows' movements by sensors. This architecture includes cloud processing and storage and facilitates to the user the cows' heat events detection and the cows monitoring through a mobile application and web application.

Primary Functional Requirements

The system architecture allows detecting cows' heat events through monitoring cows' activities by sensors. This system architecture includes cloud processing and storage and facilitates the detection of cows' heat events and cows monitoring through a mobile application and web application.

The authentication is needed to access the system, this process is made when the users log in to the web application and the mobile application. This process is handled by the authentication module.

The system includes a module where the IoT devices are managed. This module allows us to create, update, read, and delete devices.

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Cows' management is important, that is why the system include a cow's management module. This module mainly allows us to create, update, read, and delete cows through the applications.

The data module is the most important in the system. This module is mainly divided into five submodules: data acquisition, data reception, data transmission, data storage, and data analysis. Data acquisition, reception, and transmission collect the cows' activity information through pedometers and pressure sensors. Later, this information is sent to the gateway. The gateway consolidates all data and transmits the information to the cloud. Data storage and analysis store all sensor data in the cloud and later, this information is analyzed looking for heat events. After data is analyzed, warnings and notification are created and recorded. This allows the web and mobile application to present historical data and notifications to de final user.

Finally, the system includes a module that allows monitoring the system's performance and parameterizes the system. This module is mainly divided into the system's alarms, system's logs, system's parameter, and device status.

Quality Attributes Scenarios.

The system's quality attribute scenarios are mainly divided in performance, security, reliability, availability, maintainability, and portability.

Performance. The system must be able to process up to 1000 connected devices simultaneously, allow up to one hundred users using the user interface at the same time and the user interface latency must be lower than 3 seg.

Security. All transactions between client-server must be authenticated, all communication protocols must include security tier, and devices access must be authenticated.

Reliability. The gateway must ensure that no message is lost. The system must be able to restart without any information losses and start all the processes in automatic way after a restart. The synchronization between services must be automatic.

Availability. The system must be available any time with all features and processes running throughout web applications and mobile applications. Besides, showing the device status at any time.

Maintainability. The system must be able to run services independently. In case some service fails, all of them must stay running. Besides, all processes must be able to run manually and automatically. The system must be able to allow partial updates and be scalable in all services.

Portability. The system must be accessible in any web browser and mobile devices with the Android operating system.

Constrains

The constraints considered are mainly divided into application access, device communication, store, and processing.

Design Concerns.

The system architecture will be based on a greenfield system and based on services provided by AWS.

B. System Architecture

The system architecture is based on a Service Oriented Architecture style principle: standardized service contract, service interoperability, service abstraction, Service autonomy, service composability, service discoverability, service loose coupling, and service statelessness. These principles allow supporting input drivers.

The architecture mainly divided into three layers: IoT device, ingestion and analysis, and presentation. That, it been shown in figure 1.

IoT Device Layer

This layer collects the cow's steps quantity and the time when the cows are lying or standing. This information is consolidated in a gateway and sent to the ingestion and analysis layer using the Message Queuing Telemetry Transport (MQTT) protocol.

Ingestion and Analysis Layer

This layer is hosted in the cloud and receive the information sent by the IoT device layer. This information is stored in databases and afterward processed and analyzed to identify heat events. The result of the analysis is stored in databases then accessible by the application layer. The main characteristics of the ingestion and analysis layer are the possibility to provide historical and real-time data.

Presentation Layer.

This layer is responsible to show the final analysis results to the final user. The analysis results are shown through notification and statics in the web and mobile applications.

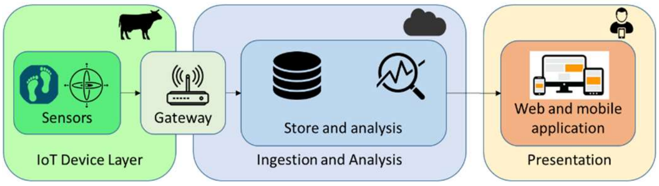

Fig. 1. System architecture with three layers: IoT device, Ingestion and analysis and Presentation.

The system implements a big data architecture pattern since it will process a lot of information. The selected architectural pattern is lambda architecture. This architecture unifies online processing and batch processing in one framework, it is fault-tolerant, its information is immutable, and it is easy to be reconfigured. This architecture is mainly divided into five components: data stream, batch layer, speed layer, serving layer, and query. Figure 2 illustrate the lambda architectural pattern addressed in the three-layered system architecture proposed.

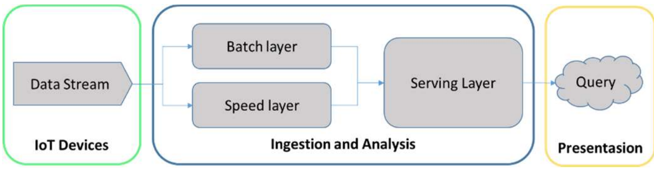

Fig. 2. System Architecture based on lambda architecture and the three-layered architecture proposed.

AWS services are considered components in the system architecture and addressed in the three layers (Fig. 3). Next is detailed the set of responsibilities of the layers' components.

Data Stream.

The data which is consumed in the system is generated in the IoT device layer, this is mainly divided by IoT devices and Greengrass service.

IoT devices (1). The IoT devices collect the data information from the physical variables required to determine the heat event. The physical variable is the movement and is measured by pedometers and pressure sensors. The IoT device determines the steps quantity and the time when the cows are lying or standing.

Greengrass (2). Greengrass is a gateway and consolidates the information sent by IoT devices and sent this information to the cloud.

Speed Layer

This layer processes the data sent by Greengrass and creates data sets that are consumed by batch layer and speed layer. This layer includes AWS IoT Core, AWS IoT Analytics, AWS Events, and Amazon Simple Notification Service (SNS).

AWS IoT Core (3). This service receives the data sent by Greengrass service using the MQTT protocol. In this service, all IoT devices connected to the system are configurated. It generates rules which allow sending the data to de AWS IoT Analytics service.

AWS IoT Analytics (5). This service process and analyzed the data. AWS IoT analytics performs three main processes: Collect the information from IoT devices trough a channel connected to AWS IoT core, transform the information, enrich the messages, and finally stores the data.

AWS Events and SNS (9). This service analyzes the data, if it detects a heat event, then triggers alarms.

Batch Layer

The batch layer allows processing information analyzed and stored previously running each 30 minutes the heat event detection process. This layer is mainly composed of an Amazon notebook.

Amazon Notebook (7). Once the data sets are ready to be analyzed, it is triggered a process that executes a notebook. Notebook contains the algorithm's code which analyzes the information and determines whether there is a possible heat event or not. Each time when the process is triggered, the analysis results are stored in databases to be accessible in the web and mobile application.

Serving Layer

This layer store and provide the data to the web and mobile application. It is mainly composed of five services: relational databases service (RDS), no relational databases (DynamoDB), Amazon Simple Storage Service (Amazon S3), Amazon API Gateway, and Amazon Cognito Pool.

Lambda functions (10). Lambda function transforms the information stored in the databases to json format and provides easy access to the data.

RDS (11). This service stores the results of data processing and the relation between sensors data and the cow's number. This service allows us easy access to historical data.

DynamoDB (12). It is a non-relational database, and it is used to store raw message data, allowing to have available information in case that reprocessing is needed.

Amazon API Gateway (14). It is the service that provides the information to the web application and mobile application using RESTful requests. This service implements lambda functions that read the information from RDS and DynamoDB services. To protect the system against any threat, the architecture implements the authorization and authentication service Amazon Cognito User Pool.

Amazon Cognito User Pool (15). This service manages user access and creates an access token. This access token is later used in RESTful requests.

Query.

Mobile and web applications allow the user access to graphs, tables notifications, and general information regarding cow's status.

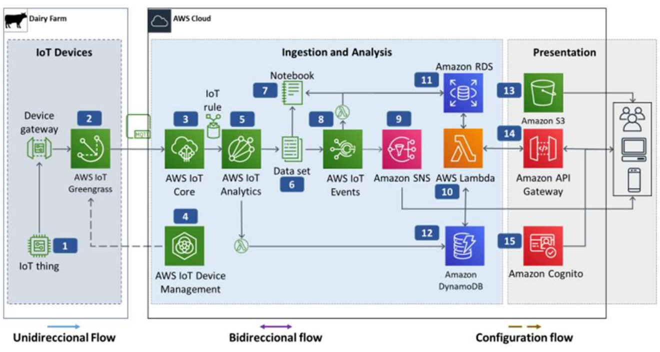

Fig. 3. AWS services addressed in the three layers: IoT devices, Ingestion and Analysis, and Presentation.

C. *Advantage of the System Architecture*

Compered with the collar presented by Bellini and Arnaud [22], the proposed architecture implement each services running in the cloud, this allows the remote monitoring and present high accessibility since the mobile application and the web application can be accessed in multiple devices.

Compared with the fog computing assisted application system for animal behavior analysis and health monitoring in a dairy farming scenario by Taneja et al [11], AWS IoT Analytics service and Notebook service which are the main elements in the system architecture to process the information and detect the cows heat event have the advantages of dynamic scalability, high availability and reduce the Hardware implementation.

The advantages of the system architecture proposed are describe as follows:

Scalability

The services are implemented in the cloud. This allows to increase the or decrease the performances and resources depending in the devices connected to de system. Besides, Notebook service can implement different kind of algorithm to detect the heat events.

Security and Reliability

Amazon Cognito provides authorization and authentication increasing the system security, furthermore, AWS IoT Greengrass ensure all messages sent by sensors are delivered to the cloud, increasing the reliability.

Portability and Availability

The web application and mobile application allows the access through different kind of devices, such as mobile phones, desktop computers, laptops, tablets, and so on. The system architecture has high availability since all services are running in the cloud 24/7.

V. CONCLUSION

Internet of things and cloud computing can help us to systematize processes performed in manual or traditional ways. This systematization in dairy farms allows remote monitoring and easy management of cows, reducing the losses due to missing heat events.

The system architecture presented in this paper allows to implement a system with low Hardware implementation since it is supported in cloud computing, it reduces the cost of implementation and it can be used in dairy farms where the budget dedicated to systems and autonomous tasks is limited. This system architecture is scalable and allows to increase easily and quickly the number of users and sensors connected to the system.

According to the features of the IoT, LoRa protocol and mobile application increase the system's accessibility, whereby the system can be used in many dairy farms with different characteristics, allowing them to increase the use of the system.

According to the cloud computing characteristics and the services available in AWS, this system architecture easily allows integration of new features in the system, offering attractive tools for cows' production and reproduction managements.

The system architecture proposed support the heat detection, which is a part of reproduction process. This process is one of the most critical in the dairy farms and sometimes performed manually. Further features of the presented architecture could fulfill the reproduction process systematization. Besides, having the information centralized in the cloud, it is possible to use this information in smart farming application.

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