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A Smart Monitoring System for a Future Smarter Dairy Farming

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***Abstract*— The study presents the objectives, methodologies and technical features of a monitoring system designed in the context of a national research project proposing innovative technical solutions for smart dairy farming in order to increase the herd productivity. The main objective of the project was to improve environment conditions and animal welfare of dairy cows and consequently enhance reproduction and production. To this regard, the system described here has a fundamental role operating as a tool for a more efficient management of the herd and of the herd housing. In fact, in the last years, animal control techniques and farm environmental monitoring have been developed, with increasing intensity, through the integration of Information Communication Technology (ICT) systems and models for the analysis and interpretation of the data collected. In this field, the Smart Monitoring System (SMS) described here could be effectively implemented in order to increase the animal welfare but at the same time increase the animal production. The integration of different type of sensors, different type of data and different type of models is at the base of the modern techniques for herd management and of the tools aiming to increase the dairy sector sustainability. The system integrates specifically designed sensor networks in a customized system architecture. It allows the acquisition of big data time series about physical and environmental conditions of the facilities hosting the cow herds starting from the collection of both indoor and outdoor environmental features, enabling a smart control of the facility, a diagnosis of the operating conditions, and early alerts in case of anomalies. The system has been developed to work in several environmental situations and is able to make the data remotely available in real time in a cloud.**

Keywords*— *ICT, dairy production, LoRaWAN, smart monitoring system

I. INTRODUCTION

Information science and information technology are having a rapid growing impact on the methods used in livestock production. Precision livestock farming (PLF), which is based on these concepts, is just an example. Using electronic information transfer, PLF applies engineering control in optimizing the production and the management processes.

PLF consists in measuring specific features of the animals, modelling the acquired data to obtain useful information, and then using these outcomes for real time monitoring, prediction and control purposes. In fact, in the last years, animal control techniques and farm environmental monitoring have been developed, with increasing intensity, through the integration of Information Communication Technology (ICT) systems and models for the analysis of the data collected [1]. Then, weather stations monitoring barn temperature and humidity, robotic milking systems helping the daily work of the farmers, collars and pedometers controlling animal's activities and positions [2]-[3] are today capable to collect huge amounts of real-time data currently used to support the herd management.

PLF has contributed to switch the analysis framework of a farm from a data-poor to a data-rich situation. Today, thanks to both the PLF algorithms and the huge data set coming from barn and animals, it is possible to obtain useful indications for the farm management producing benefits in terms of animal welfare , animal productions, environmental sustainability, energy use reduction [4] and consumers' awareness [5]. Therefore, PLF is increasingly applied also in dairy cattle sector, for the control of qualitative and quantitative production parameters, real time control of the single cow position, behavior and animal welfare [6].

The current research key challenge is to turn those data into knowledge able to provide decision-maker with real time support for the cattle farm optimization [7]. In this context the research project "Smart dairy farming: innovative solutions to improve herd productivity" [8] has among its objectives the development of a system that integrates specifically designed sensor networks in a customized system architecture, which

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allows the acquisition of big data time series about physical and environmental conditions of the facilities hosting the herd.

The availability of new information coming from the elaboration of large amount of data and the introduction of sustainable and energy efficient applications [9]-[10] will represent two key aspects in the future of livestock sector.

II. Description of the Project

PLF is currently at the base of the engineering applications aiming to improve the sustainability in the food production sector. Actually, there is a great potential in developing technology for continuous automatic monitoring to predict and improve animal health and welfare and at the same time it allows to make optimal use of resources, knowledge and information in the monitoring, prediction and planning of the processes.

In this context, the general goal of the aforementioned project "Smart dairy farming: innovative solutions to improve herd productivity" is to identify the relationship among environmental conditions, behavior and state of individual cows, and to find innovative solutions to ensure dairy cow welfare by the appropriate management of in-house environmental conditions. The 3-year project is structured in six different linked tasks each one representing a specific target, and is developed under the collaboration of four Italian University: University of Milan, University of Catania, University of Florence and University of Bologna.

To fulfil one of the goals of the project, a specific customized monitoring system has been developed and then designed. The heterogeneous data to collect and the particular environmental conditions of the facility hosting the system have driven the sizing and the technology to adopt during the design phase. The system idea comes from the development of similar successful projects, in which the remote monitoring networks have been applied in different typologies of agricultural and productive facilities.

Thanks to the monitoring system described here, realized and installed in a prototype version and actually working in a productive case study barn, we are collecting different, indoor and outdoor, environmental data allowing to:

- monitor the features of the barn hosting the animals and judge in real time the animal welfare;
- correlate indoor and outdoor environmental parameters;
- analyse and evaluate possible correlations between the data of cow production and cow activity with the indoor environmental data.

III. Description of the Smart Monitoring System

The Smart Monitoring System (SMS) integrates specifically designed sensor networks in a customized system architecture. It has been designed for the acquisition, storage, Wi-Fi transmission and management of large datasets of physical and environmental features collected in a barn, enabling a smart control of the facility, a diagnosis of the operating conditions, and early alerts in case of anomalies.

The system has been developed to work in several environmental situations, in different climatic conditions, and is able to make the data remotely available in real time in a cloud. All this allows the system to be flexible for future application in productive contexts, also based on the physical quantities to be measured, the accuracy and sensitivity needed, and energy and internet connections available.

None of monitoring system available on the market was suitable for farm applications due to the specificity of the features and variables to record, the need to change the acquisition time interval in certain circumstances, the position and the environment of the probes acquiring the information. Therefore, the SMS design has focused on the identification of the most suitable sensors, networks, protocol for data transmission in order to obtain an efficient and cost-effective solution.

The SMS has been designed and built as a system capable of measuring the main environmental outdoor and indoor data (T, rH, pressure, gases concentration, wind velocity and direction, etc.) and other quantities, and to manage and remotely send the acquired data in real time.

For what said above, the heterogeneity of data and locations entails that a wireless communication technology is needed. In some circumstances, the use of power grid is unavailable, therefore acquisition devices must be off grid supplied by batteries and assisted, where possible, by the use of an energy harvest from photovoltaic solar panels.

Finally, in order to create a system able to address all the proposed challenges, the system must be flexible and easy to install, modify and manage. Therefore, the system is thought to be composed by a central unit (gateway), connected to the internet and to the power grid. The central unit communicates wirelessly with nodes that can be connected to the grid or operating with a battery. The nodes are similar in all the environments and manage the sensors (probes). In this configuration, the SMS can handle all the data locally; for the data transmission, the gateway sends data to a remote server and then to a cloud using the internet, in order to make them available remotely and in real time.

The needs and characteristics of the scenarios in which the monitoring system could be applied have been identified and listed as follows:

- medium/low frequency of acquisition of environmental physical quantities;
- suitability for the installation of the monitoring system in heterogeneous environments often distant from a cable or Wi-Fi Internet connection;
- constraints due to low energy consumption for battery operation which guarantees a long period of maintenance-free operation.

A. Architecture

The monitoring system is made by three main hardware: "nodes", "gateway" and "server", nodes and gateway are placed in the monitored facilities, the server is placed in the University of Bologna (Italy). In addition, the server copies data on a cloud service to improve data availability and as a backup copy. Nodes are locally and wirelessly connected to the gateway that collects data and send them to the server via the internet.

The hardware device called "node" is able to acquire one or more physical quantities of interest via on-board sensors or commercial sensors. The node in fact is designed to have the possibility of interfacing with the most widespread

commercial sensors. The node is made by an electronic board provided with a small processing and storage capacity. The board manages the power supply of the entire node and sensors, battery charging and energy harvesting from photovoltaic solar panels. It is provided with wireless transmission capacity to the gateway.

The gateway is a device connected to the internet and manages the reception of data transmitted by the nodes and forwards data to the remote server. The gateway has no storage capacity but only acts as a bridge between the wireless local area network used by the nodes and the cloud server. Due to its characteristics, the gateway must be connected to the power grid. The server is a machine accessible via the internet where information from the nodes are saved, then make them accessible via the web interface. It allows to consult charts, control dashboards and download data to allowed users.

B. The nodes

An electronic device is created able to acquire information relating to different physical quantities via sensors. Based on the specific size related to the particular application context, the appropriate sensors will be chosen among custom or commercial solutions. For this reason, the node will be equipped with the most widespread communications interfaces for sensors, such as serial UART, I2C, SPI, Modbus on RS485, analog interfaces in 4-20mA current and in 0-10V voltage.

In order to make the monitoring system flexible for installation in different application scenarios, it was decided to apply a battery with adequate operating capacity. This can be recharged either from a 5 V wired power supply or from a photovoltaic panel. The useful life of the node, if powered by a battery, depends on how the information is acquired and transmitted in relation to the particular application context in which it is used and the transmission speed. An adjustment to optimize the working life will be performed after installation as expected. Once the information has been acquired by the sensors, the node has the possibility to process and temporarily store it.

The basic operation of the node concerns the acquisition of the information detected by the sensors, the execution of small elaborations on board, the transmission of the detected data to the gateway of the structure. After installation, a trial period for calibration and validation of measurements was planned.

C. The gateway

Because of the dimensions of the housing to monitor with the SMS, it was decided to organize the architecture of the system by providing a gateway as the only Internet access for the all system. In this way, it has been avoided to equip each node with a GSM connection with a corresponding subscription, (potentially very expensive in the long run), poorly performing and difficult to scale.

For these reasons, low power radio technology was chosen on the ISM band with LoRa modulation. In addition, to maintain excellent scalability and flexibility in distribution, the implementation of the top-level communication protocol, LoRaWAN, based on this technology was chosen. This technology is open and needs to be connected to GSM operators, demonstrates very low energy consumption compared to GSM or WiFi technologies, finally allowing battery operation for long periods. In particular, the technology chosen:

- allows you to reach distances in the order of one kilometre;
- has a low bps bandwidth transmission capacity but adequate for the monitoring context of interest;
- requires the use of a gateway that acts as a bridge between the local radio network and the Internet capable of forwarding the information received from the nodes to the cloud.

The LoRaWAN network topology is based on a "star" structure, which means that each node communicates solely and directly with the gateway. Each transmission received is forwarded by the gateway to a server in the cloud, which takes care of decoding information and saving it permanently and securely. In this configuration the gateway does not keep the information received in memory but transmits it directly to the server via the Internet.

To allow proper operation, the gateway must be in a suitable position to optimize the reception of transmissions and must be powered by the grid.

IV. DESCRIPTION OF THE CASE STUDY

A prototype of the SMS has been installed in a farm adopted as the study case for data collection, test of the methodology developed, and interpretation of the results. The case study considered in this work is the dairy cattle barn of the Azienda Agricola Piazzi, located in Budrio (Bologna), in the North-East of Italy where about 70 Holstein Friesian cows are reared. The dairy farm has ordinary production features.

The barn presents a 51 m long and 23 m wide rectangular plan layout, with SW-NE-oriented longitudinal axis, ridge height of 8.52 m and gutter heights of 4.95 m on the NW side and 6.65 on the SE side. It consists of a hay storage area on the SE side, a resting area in the central part of the building, and a feeding area with feed delivery lane on the NW side.

The resting area, whose floor was partially slatted, hosted 78 cubicles with straw bedding where the lactating cows are housed; two blocks of head-to-head rows were located in its central part, and another row runs along the entire length of the resting area. Ventilation is controlled by three high volume low speed (HVLS) fans with five horizontal blades which were activated by a temperature-humidity sensor situated in the middle of the barn. Lactating cows are fed with total mixed ratio kept available along le feeding lane.

Cows are milked using an Automatic Milking System (AMS) "Astronaut A3 Next" (Lely, Maassluis, The Netherlands), placed at the SW end of the animal housing area. The robot is programmed to assure a number of daily visits for each cow depending on her productivity and her expected optimal milk yield per visit, with a minimum of two and a maximum of four daily visits as constraints. Animals with less than two visits in one day were signaled by a warning, while the cows which have been milked four times in one day can only pass through the AMS box without being milked and fed inside it. The milk room was located on the SW side of the building, next to the offices and technical plant rooms. The robot also managed the supplement feeding which is calculated based on daily milk yield and day of lactation.

The SMS has been installed in the housing as showed in Figure 1. Twelve nodes are currently collecting data from the barn and the outdoor environment and the acquired information are saved, in real time, in a server of the University of Bologna.

The first results collected by the monitoring system will be soon available. In order to manage in a more simple both the nodes and the gateway of the monitoring system, a user-friendly graphical interface has been developed and created. By means of this interface it is possible to check in real-time every node of the systems and to visualize the values of the parameters detected by the system. Just as a general example, in Figure 2 is showed a picture of the interface with indicated the values of the parameters monitored by the selected node.

(a)

(b)

Fig. 1. Pictures of the SMS installed in the case study barn. (a) View of the sensors placed at the level of 2.5 m; (b) Detail of a node positioned at the level of the animals.

Fig. 2. Picture of the graphical interface used to manage the nodes and the gateway of the SMS.

V. Final Remarks

In the context of a national research project focuses on the dairy sector, a smart monitoring system has been designed, developed and the tested. Its application for the monitoring of the main environmental features of the barns hosting cow herds contributes to obtaining information on the environmental parameters of the housing (air temperature, air humidity, gases concentration, etc.) and outdoor environmental parameters.

The information provided by the SMS proved to be fundamental for increase the sustainability and the efficiency of the dairy sector, since this type of system, allow to:

- monitor and collect data, to reduce human surveillance on the facility;
- create local and remote databases;
- increase operational precision by providing data to evaluate the reduction of the environmental impact and possible benefits.

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