E. Santolini *et al*., "Monitoring and Analysis of the Gaseous Emissions Collected in a Livestock Farm," *2022 IEEE Workshop on Metrology for Agriculture and Forestry (MetroAgriFor)*, Perugia, Italy, 2022, pp. 28-32.

https://doi.org/10.1109/MetroAgriFor55389.2022.9965065

Monitoring and Analysis of the Gaseous Emissions Collected in a Livestock Farm

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***Abstract*— The study presents the preliminary results of air monitoring process in a dairy farm by a monitoring system designed in the context of a national research project. This study, in particular, aims at developing innovative technical solutions for smart dairy farming in order to increase the herd productivity. The monitoring process, in fact, allows to improve environment conditions and animal welfare of dairy cows and consequently enhance reproduction and production. To this regard, the smart system involved in the study has a fundamental role operating as a tool for a more efficient management of the herd and of the herd housing. In this field, the Smart Monitoring System (SMS) used here has been effectively implemented in order to increase the animal welfare but at the same time increase the animal production. This system, which presents different type of sensors, allows collecting different type of data, giving the opportunity to control and elaborate the barn environmental conditions aiming to increase the dairy sector sustainability. 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. This data collection process allows to carry out a diagnosis of the operating conditions, and early alerts in case of anomalies, as presented in this study. This approach and its results can be useful to understand the seasonality conditions in dairy farms with the goal of improving animal welfare.**

Keywords — dairy production, smart monitoring system, environmental microclimate, animal welfare, gaseous emission.

I. INTRODUCTION

Livestock production increasingly features the use of information science and information technology as a support for the production and management. An example is the Precision livestock farming (PLF).

Italian Ministry of Education, University and Research [20178AN8NC]

PLF deals with the monitoring process of specific environmental parameters and/or 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, recently animal control techniques and farm environmental monitoring have been increasingly performed through the integration of Information Communication Technology (ICT) systems and models for the analysis of the data collected [1]. Nowadays, a huge quantity of real time data is collected by means of several instruments such as 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]. These data currently are used to support the herd management.

PLF has helped to modify the analysis framework of a farm from a data-poor to a data-rich situation. Then, the PLF algorithms and the huge data set, coming from barn and animals, allow to get 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]. One of the sector where PLF is increasingly applied is the dairy cattle sector, for the control of qualitative and quantitative production parameters, control of the single cow position, behavior and animal welfare [6]. However, the quality of the monitoring system and then of the available data play a key role.

The current research key challenge is to elaborate the information obtainable from this process and then to analyse them to derive and turn those data into knowledge able to be a support for the cattle farm optimization [7]. In this context, this work focuses on the application of a system integrating specifically designed sensor networks in a customized system architecture, and then on the analyses of the acquired big data about physical and environmental conditions of the facilities hosting the herd.

The availability of new information derived from the elaboration of significant amount of data and the introduction of sustainable and energy efficient applications [9]-[10] will act as key aspects in the future of livestock sector.

In the context of the project "Smart dairy farming: innovative solutions to improve herd productivity" a customized Smart Monitoring System (SMS) [11] has been developed, designed and then installed in a productive environment. The most of the attention in the development of the SMS has been devoted to the careful collection of indoor data regarding air quality and air velocity forasmuch a proper ventilation is a crucial aspect in the livestock buildings and it is fundamental to guarantee a comfortable environment with satisfactory indoor air quality. In fact, the ventilation is the most efficient way to remove undesirable air pollutants, like harmful gas and dust, and to obtain a comfortable microclimate for the welfare of the animals [12]. To create an optimal microclimate, the most important indoor environmental parameters to monitor are: air temperature, relative humidity, gas concentration, air velocity, lighting, air pressure, and noise [13].

II. Description of the Smart Monitoring System

In the context of the aforementioned project "Smart dairy farming: innovative solutions to improve herd productivity" a customized Smart Monitoring System (SMS) [11] has been developed, designed and then installed in a productive environment. 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 SMS, 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.

The 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:

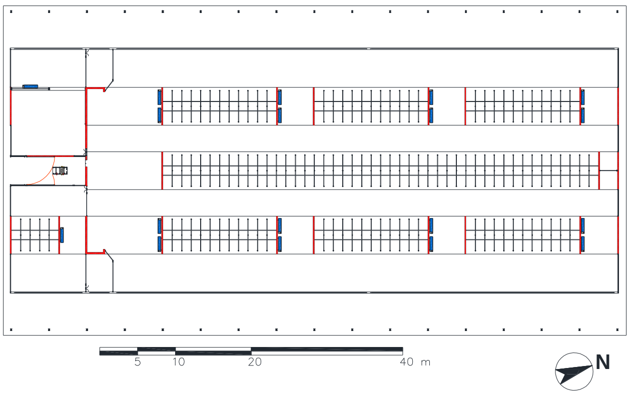
- medium/low frequency of acquisition of environmental physical quantities;
- suitability for the installation of the monitoring system in heterogeneous environments often distant from a cable or Wi-Fi Internet connection;
- constraints due to low energy consumption for battery operation which guarantees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

III. Description of the Case Study

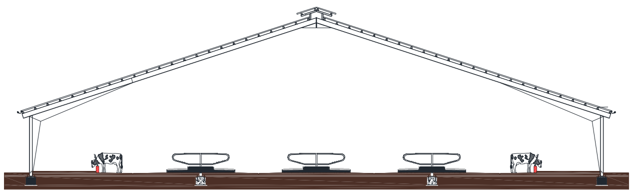
A prototype of the SMS has been installed in a farm adopted as the study case for data collection, test of the methodology developed, and interpretation of the results. The case study considered in this work is the dairy cattle barn of the Azienda Agricola Montagnini, located in San Pietro in Casale (Bologna), in the North-East of Italy where about 270 Holstein Friesian cows are reared. The dairy farm is a new modern barn for lactating cows. The barn building, is located in the Emilia-Romagna Region (in the North of Italy), in a plain countryside about 25 km North of Bologna (WGS84 coordinates 44°42'59.2"N 11°27'04.9"E, 17 m a.s.l.). The barn (see Figure 1), has rectangular plan layout with dimension of 42.22m×80.30m, the longitudinal axis (i.e. the longer dimension) is SW-NE-oriented with -20° azimuth angle (see Figure 2).

The inner part of the barn represents the resting area where, closing fences along the symmetry axis allows to subdivide the herd into two groups, as both the resulting parts of the barn can be independent. The elevation of the building creates a symmetrical double pitched roof with no internal column, with ridge along the longitudinal direction. It has 33% slope, height at eaves of 4.00m and ridge height of 12.15m, with continuous ridge opening (see Figure 1). The long sides of the building are open, to enhance natural ventilation for both displacement and stack effect.

Indoor thermo-hygrometric conditions are controlled also through forced ventilation, by means of high-volume low speed fans with horizontal blades, activated by a temperature-humidity index (THI) sensor situated close to the barn center. Further cooling benefit is achieved through low-pressure, large-droplet water soaker lines installed above the feeding lanes.



(a)



(b)

Fig. 1. Plan view (a) and transverse cross-section (b) of the case study barn.

This sprinkler system completely wets the cows by soaking the hair coat and it proved to reduce the body temperature and improve the dry matter intake, the conception rates and live calf birth rate. A pipeline is thus installed next to the feeding area and mounted with low pressure 180° nozzles with spray pattern with a radius of max. 2.50m, which is suitable to avoid wetting the cubicles bedding. Spraying is activated when THI measured in the barn is over a specific threshold. Cows are milked using four Automatic Milking Systems (AMS) "Astronaut A3 Next" (Lely, Maassluis, The Netherlands). The robots also managed the supplement feeding which is calculated based on daily milk yield and day of lactation.

The SMS has been installed in the building as showed in Figure 2. Fourteen nodes are currently collecting indoor data whereas one is collecting outdoor environmental data. The indoor nodes record: temperature, relative humidity (rH), air velocity, and the concentrations of CO_2, CH_4, NH_3, H_2S, SO_2. The outdoor node acquires: temperature, relative humidity, air pressure, wind velocity, wind direction, rainfall, illuminance. The acquired time series are saved, in real time, in a server of the University of Bologna.

IV. Main Results of the Monitoring

In order to manage in a more simple way 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 3 some pictures of the interface with indicated the values of the parameters monitored by the selected nodes are showed. The results of the monitoring of the first year of project, with data collected by the SMS, are available and synthetically reported in the following. As described before the undesirable gas concentrations mostly influencing the air quality in livestock buildings are carbon dioxide (CO_2), ammonia (NH_3), methane (CH_4), hydrogen sulphide (H_2S) and sulphur dioxide (SO_2). Most of these gases are present in low concentrations in the atmosphere, but they can affect both animal welfare and animal production if the concentrations exceed specific thresholds. These aspects are much more important in buildings for intensive animal husbandry where appropriate ventilation is an essential requirement to ensure both animal welfare and efficient and sustainable production.

As far as the gas concentrations recorded in the case study barn are concerned, the Table I summarizes the most representative values.

(a)

(b)

Fig. 2. Pictures of the SMS installed in the case study barn. (a) View of an indoor node placed at the level of 2.0 m from the bedding; (b) Detail of the outdoor node located at the top of the building.

In the table are reported the minimum, the maximum the median and the 75th percentile values, together with an indicative alert threshold for the single species. As the table shows the only gas having recorded values higher than the alert threshold is the CH4 for which the maximum recorded value is 7333ppm with a threshold of 5000ppm.

This aspect provides useful indications suggesting that in the monitored period in a significant number of hours the value of methane concentration recorded in the barn exceeded the alert threshold. On the basis of these considerations, the ventilation systems should therefore in future also be operated on the basis of undesired gas concentrations in the livestock barn.

Fig. 3. Some images of the graphical interface in Grafana used to manage the nodes and the gateway of the SMS.

TABLE I. REPRESENTATIVE VALUES FOR THE MONITORED GASES

Gas	**Values in ppm**				
	Min	***Max***	***Median***	***75th percentile***	***Standard deviation***
CO_2	127.67	1016.50	411.67	507.42	143.01
CH_4	1000.00	7333.33	2633.33	3033.33	610.06
NH_3	0.00	4.50	0.67	1.67	0.90
H_2S	0.00	5.00	1.33	2.00	1.05
SO_2	0.00	0.13	0.00	0.00	0.01

Moreover, with reference to air velocity recorded in the monitored period, the Table II summarizes the most representative values. In Figure 4 is reported the histogram graphs of the values of the indoor velocity recorded during the monitored period. The most important aspect to highlight is that usually, the indoor velocity has good values. In fact, the value corresponding to the 25th percentile is equal to 0.48m/s. This usually guarantee a sufficient air exchange and a good efficiency in the removal of undesired gases. A further aspect related to the indoor air velocity can be the mitigation of the heat stress problems during the hot season. The presence of a sufficient air velocity hitting the animals can help to reduce the animal heat stress and the related problems.

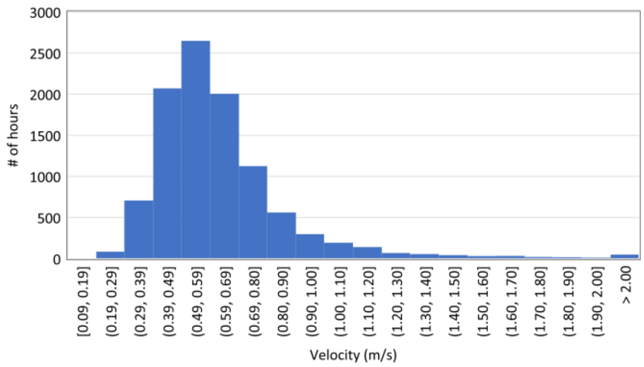


Fig. 4. Histogram graphs of the values of the indoor velocity recorded during the monitored period by the SMS.

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.

TABLE II. REPRESENTATIVE VALUES FOR THE AIR VELOCITY MEASURED DURING THE MONITORING

Air velocity	Values in m/s			
	Min	*Max*	*Median*	*25th percentile*
Outdoor	0.00	13.79	1.13	0.67
Indoor	0.09	5.57	0.58	0.48

ACKNOWLEDGMENT

The authors wish to thank the Azienda Agricola Montagnini, located in San Pietro in Casale (Bologna), Italy, for the availability and the collaboration during the survey and the research activities.

FUNDING

The activity presented in the paper is part of the research project PRIN 2017 “Smart dairy farming: innovative solutions to improve herd productivity” funded by the Italian Ministry of Education, University and Research [20178AN8NC].

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