Precision Livestock Farming: A Multidisciplinary Paradigm

Guillaume Terrasson, Eric Villeneuve, Véronique Pilnière, Alvaro Llaria
ESTIA, F-64210 Bidart, France
e-mail: {g.terrasson, e.villeneuve, v.pilniere, a.llaria}@estia.fr

***Abstract*—Since several years, Precision Livestock Farming (PLF) has experienced a significant progress mainly due to the electronics and embedded systems miniaturization, along with the Internet of Things expansion. Geolocation and animal behavior identification are common research subjects in PLF, and several solutions have been proposed in this frame. Nevertheless, the development and generalization of this kind of tools must still face up several technical and societal challenges and, in order to overcome these difficulties, a multidisciplinary work is necessary. In this context, this paper presents the e-Pasto experimental platform, which employs different smart interfaces, as a case-study to analyze the main issues related to the implementation of PLF solutions. Along with this analysis, some relevant aspects of current systems are studied and discussed from different points of view, from technological to human ones, with the aim of offering a new vision, which tries to take into account, as far as possible, the final user needs.**

Keywords-Smart Interfaces for Engineering; Data Processing; Decision-making; Systemic Approach; Precision Livestock Farming.

I. INTRODUCTION

The evolution of electronic devices, the improvement of wireless communication networks and the Internet access availability during the last years are the main reasons of the Internet of Things (IoT) expansion. Nowadays, IoT based solutions are considered a promising way to collect data that can be processed and analyzed by final users in order, for example, to supervise a manufacturing process or to monitor the health of home-based patient.

In this frame, solutions based on aggregation of technologies, such as interconnected ubiquitous objects, represent an interesting option to offer new tools that may improve livestock productivity and product quality, reducing at the same time the work hardness. Moreover, other information about animals and the whole cattle, such as physiological conditions combined with environmental data, is necessary to correctly monitor the livestock: survey of animal activity and location in large pastures and small areas, diseases prediction or detection, improvement of livestock nutrition effectiveness, productivity and quality optimization, ensuring at the same time the animal well-being. However, nowadays, the development of this kind of tools stays in a research phase because of a number of challenges that must be still faced up, from both technical and societal points of view without forgetting final user needs. In this context, the aim of this paper is to identify and analyze, using the e-Pasto platform as case-study, the different difficulties to be overcome. The need for a multidisciplinary approach to provide useful smart interfaces that allows the interaction among livestock, farmers and also the environment, based on suitable technical solutions, is also proved.

This document is structured as follows. In Section II, after a brief review of the existing research work concerning Precision Livestock Farming (PLF), the e-Pasto platform is presented together with the obtained results. Section III illustrates, considering the e-Pasto case-study, that a multidisciplinary approach, covering from technical knowledge to human sciences, is needed to face up the different found problematics. Finally, Section V concludes this paper.

II. CASE-STUDY: THE E-PASTO PLATFORM

A. State of the Art of Precision Livestock Farming

PLF consists essentially in acquisition, collection and analysis of data from each animal and its environment employing, as illustrated by Figure 1, different Information and Communications Technologies (ICTs) such as sensors, communication networks, decision-making algorithms and human-to-machine interfaces (HMIs) [1]. PLF allows farmers to access new services such as individual feeding, health monitoring, animal localization and, consequently, to conduct in a more effective way their livestock ensuring at the same time productivity, animal well-being and economic benefits.

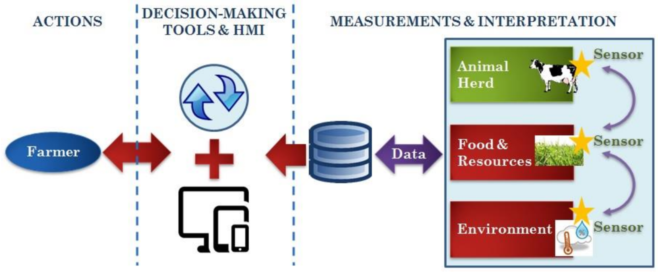

Figure 1. General architecture of a PLF solution [1].

There is a number of research works and solutions concerning PLF that can be found in the scientific literature [2]. A frequently employed solution is Radio Frequency Identification Technology (RFID), which is used to identify animals. From a regulatory point of view, RFID animal identification guarantees the traceability through the feed-animal-food chain. However, some current works and commercial solutions use also this technology in order to manage and automatize animal feeding regime or to allow the heat detection [1].

Moreover, ICT for domotics applications can be also applied to monitor the animal and to control cattle environment [3]. In barns, this kind of technology is useful to guarantee the animal well-being and health by regulating temperature, humidity and concentration of ammonia, among others. In the case of extensive farming exploitations, meteorological sensors help to predict the displacement of the cattle and, consequently, to improve their management.

In addition, accelerometer and other sensors (temperature, geolocation) are commonly used for animal's health and behavior monitoring. In the scientific literature, accelerometers and dataloggers have been largely applied to identify the animal behavior and principal activities [4]: grazing, resting, walking. This information, provided by accelerometers and coupled with a decision-making software, allows farmers to determine the welfare and health of their animals, optimizing the veterinary intervention.

Virtual fencing technologies are also a classical example of PLF solutions [5]. In extensive farming, virtual fencing combining Global Positioning System (GPS) and Geographic Information System (GIS) contributes to understand the cattle's displacements and also to enhance herd and grazing resources management. This capacity of remote monitoring allows farmers to optimize the time needed to accomplish their daily tasks, resulting in a better productivity, with a positive impact on the environment too.

B. e-Pasto Platform: Description and Main Results

In order to better illustrate what a PLF solution is, the e-Pasto platform [6] will be thereafter presented as a case-study. This solution, developed in the context of a European research project and dedicated to cattle supervision in extensive farming environments, is composed of four main parts: the motion devices, a communication infrastructure, an information system and a human-machine interface, as it can be seen in Figure 2.

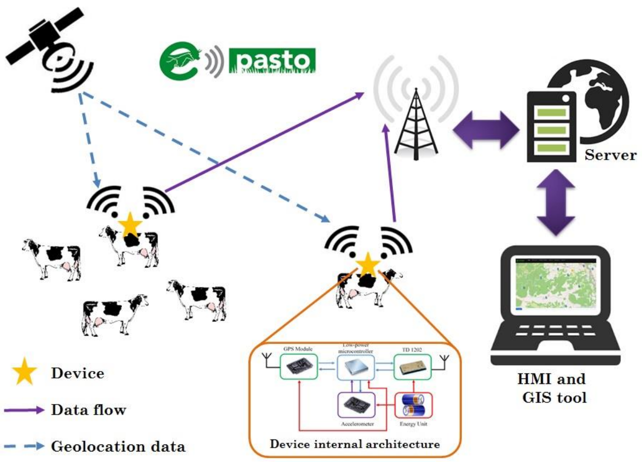

Figure 2. Global architecture of the e-Pasto platform.

The motion devices, which are directly embedded onto the animal collar, include a GPS and an accelerometer, and collect position and behavior data from animals. These data are transmitted to a remote server through the wireless communication network provided by SIGFOX$^{©}$. The aggregated data can be remotely exploited by the farmer in two different ways:

- To locate animals in mountain pastures during the summer period, allowing at the same time a better management of the cattle and the grazing resources using a virtual fencing solution.
- To measure and supervise animal behavior with the aim to warn the farmer in case of eventual disease or predation activity against their cattle.

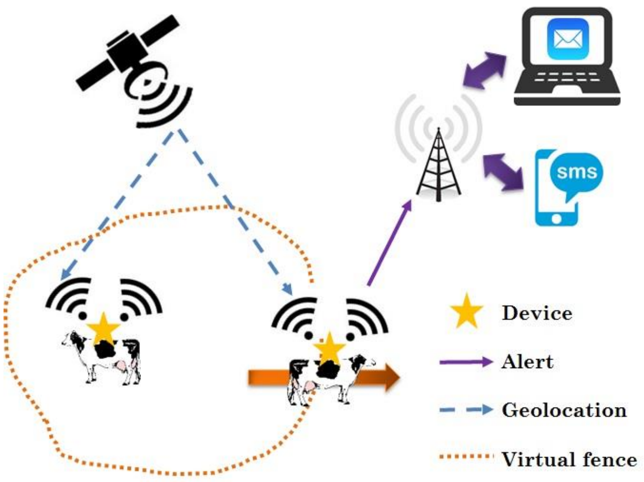

Figure 3. e-Pasto virtual fencing principle.

Real field tests were conducted in two experimental zones, one located in Ariège (France) and the other one located in Gipuzkoa (Spain), to validate the architecture of the platform and their global performances. During these field tests, the correct performance of the motion devices in terms of size, weight and autonomy was validated. More precisely, the motion devices employed in the e-Pasto platform offered a size and weight adapted to different animal species such as bovines, ovine and horses, along with an autonomy in energy generally equal or higher to 7 months, which was assured taking one location position per hour. These position data were sent afterwards through the long-range low-power consumption network developed by SIGFOX$^{©}$.

As it has been said before, motion devices include an accelerometer. It has been proved that the data issued from the accelerometer can be processed in order to detect several behavior patterns (resting, walking and running), functionality which ameliorates the animal geolocation precision [7]. By the moment, this behavior identification has been only tested on humans.

To conclude, it is important to highlight that one of the most remarkable results of the e-Pasto platform was the validation of an innovative virtual fencing solution, whose principle of operation is depicted in Figure 3. This solution allows the farmer to draw and define the size and shape of their virtual fences, using the point-in-polygon geometric computation principle, by means of the HMI developed for the platform. If an animal equipped with the motion device goes out of the limits of its authorized virtual fence, an alert message is generated at the server level and transmitted to the farmer by SMS or e-mail. Consequently, contrary to other solutions proposed in the scientific literature [5], the e-Pasto virtual fencing solution is not based on a remotely application of negative cues (vibration, electrical stimulation) to induce a movement when the animal is detected out of the limits of a virtual fence. Instead, once the farmer is warned, he has the liberty to take a decision about how to solve the problem with the concerned animal.

III. DISCUSSION OF MAIN ISSUES

As it has been seen in previous sections, the application of PLF solutions based on ICTs seems to be an attractive way to motivate people to work in agriculture and livestock domains, by offering tools that improve productivity and product quality, reducing at the same time the work hardness and ensuring the animal well-being. In addition, the current changing context about intensive farming methods, implying a constant evolution of legislation, ethical issues and economic challenges, together with global warming, makes PLF solutions an interesting support to assist farmers in their decision-making process.

This section, always with the e-Pasto platform case-study, the state of the art and the current context in perspective, will highlight the main challenges and issues that PLF solution providers have to face up to generalize these solutions, applying a multidisciplinary approach.

A. Technical Challenges

From a technical point of view, several issues at different levels of a PLF solution can be identified.

1) Data collection and transmission

As illustrated by Figure 1, PLF solutions are based on the automation of data aggregation and transmission, not only at the animal level but also at the environment level [1] [3]. This way, technologies involving embedded electronics and sensors are very often used to capture the information needed for PLF applications.

First of all, accuracy and reliability of the collected data are major issues that directly impact the design of embedded electronics devices. In the frame of the e-Pasto platform, where animals have to be located in an outdoor wide area of 2000 hectares, it can be acceptable for end users a precision around 10 meter using GPS technology. On the other hand, when animals are located in an indoor environment such as barns, the employ of GPS is not reliable and, in addition, the technology to be used for animal geolocation should assure a more accurate position measurement, in the order of centimeters. Consequently, as shown by these simple examples, the election of the location measurement technology depends on several parameters like the environment, the sort of animal or even the application.

Data transmission in outdoor or indoor real environments is also a complex task due to eventual multipath propagation, shadowing, or signal attenuation [2]. Therefore, the choice among current communication technologies, such as Wifi, cellular telephony or ZigBee, in example, must take into account many aspects like data range, quantity of data to be transmitted, indoor or outdoor environment, always with the goal of minimizing any loss of data, which could perturb the overall reliability of the PLF solution.

Finally, it must be pointed up that the main challenge concerning data collection and transmission is to achieve an optimal trade-off among different aspects: accuracy, reliability of data collection and transmission, together with acceptable size and weight of embedded devices carried by animals in harsh environments, offering at the same time enough energetic autonomy to assure the correct operation during long periods of time [6].

2) Processing and exploitation of the data

The processing and the exploitation of the collected data within the framework of the e-Pasto platform are intended to help breeders in their decision-making process in order to improve their management of livestock placed in mountain pastures.

In addition to data issued from sensors placed on animals (geolocation, accelerometer, physiology, etc.) and mapping of the pastures area, the decision support mechanisms can use numerous additional data such as:

- Topographic data to qualify areas suitable for feeding livestock but also risky areas (cliffs, rocks, etc.).
- Data derived from the expert knowledge (breeders, scientists, mountain guides, etc.) to identify hazardous or accident-proning areas, protected areas for environmental reasons, as well as information about predators (attack locations, predator identification...). It is also possible to integrate collaborative aspects into the e-Pasto platform to allow an exchange of information between breeders and thus have expert knowledge updated more regularly and about wider areas.

Consequently, the data capitalized by this kind of PLF platform are diverse and can represent a large volume of information. The heterogeneity and the amount of data collected highlight several challenges that will need to be addressed to develop a powerful decision support tool.

Firstly, the diversity of capitalized data and their potentially random reliability [3] (failure of sensors, human errors, etc.) implies to choose a formalism adapted to the modeling of uncertain and heterogeneous knowledge. There are many tools relevant to this problem. For example, Case-Based Reasoning (CBR) [8], Constraint Satisfaction Problems (CSP) [9] or Bayesian networks [10] allow to cover part of the needs. Many methodologies linking several of these approaches to address the problem in its entirety are available in the literature [11].

Secondly, capitalized data can be used in several ways. The first possibility is to visualize the raw information on the map, such as the location of the last predator attacks, the protected areas or the current position of the livestock. These data alone help the user to decide. For example, when positioning a virtual fence, it may be useful to know if there has been a predator attack in the area. Another use may be to pre-process the data to obtain additional information [3]. For example, it would be possible, with time-based geolocation data, to identify overexploited areas to allow the farmer to act accordingly. A last way of using this data could be a virtual assistant, which, depending on the choices made by the breeder when using the platform, would offer additional information enabling him to refine his decision. For example, if the user defines a virtual fence too close to a risk area, the software would suggest an alternative positioning.

Finally, a major issue in decision-making is the level of autonomy of the tool. It is possible to propose a solution which, based on the capitalized data, calculates and decides alone the procedure to be followed (for example, define automatically virtual fences). An alternative to this kind of tool lies in the suggestion by the tool of possible choices for the user (based on the capitalized data) but leaving him the final decision. This major design choice is a very important criterion for the acceptance and therefore the use of the tool by the breeders [12].

B. Challenges for Users

If a closer look at the challenges induced by technological innovations in the agricultural sector is token, the e-Pasto platform finds its place. Indeed, looking at the evolution of the agricultural sector since the 1950s, there is little in common with practices applied today. The agricultural sector is constantly evolving (decrease of agricultural occupation for 50 years, evolution of agricultural policy, etc.). Being a breeder 50 years ago is no longer the same thing today. The evolution of farmers' practices is accompanied by a change in their needs. This aspect refers to a broader issue: what are the users' needs? Identifying the needs of users is inherent to technological developments. One of the reasons for this importance is that if the system does not satisfy a need, it will not be used by the user [2].

In addition, behind all these elements, for the farmer the question is: what is the impact of the technology on his daily tasks? In order to define the daily tasks, researchers and designers must precisely list different work situations of farmer and see with the farmer which of them are easy or difficult to do. Researchers must also understand what the work of the farmer is. A farmer cannot be forced to use a system that involves more constraints in his work than facilities. It is the system that must be adapted to the user, not the opposite.

Furthermore, many other important aspects should be considered: to be farmer in a country A is not the same thing that be farmer in a country B, and the needs of young farmers are different from those of very experienced ones. In addition, the farmer is not the only one user: animals must be also taken into account. For example, behaviors of cows in a cattle are different from one animal to another. All these aspects lead to define plenty of different work situations [13] [14]. Once these work situations defined, researchers and farmers will be able to dialogue and find solutions adapted both to the farmer and the animal. The found solutions must be always a trade-off between possibilities, constraints of daily work and technology.

Finally, it should not be forgotten that the agricultural sector is in continuous evolution. Thus, it is necessary to think about changes and the technological system could take into account these changes, creating a virtuous circle. To make a change, it is crucial to identify users in the earliest phases of the project and also integrate them into the development process.

IV. CONCLUSIONS AND PERSPECTIVES

The work presented in this paper has presented some basic characteristics of PLF systems, showing at the same time the main contributions of the e-Pasto platform to these area, but not only: this article tries to initiate an exhaustive reflection concerning smart interfaces and their empowerment capacity, described in Figure 4.

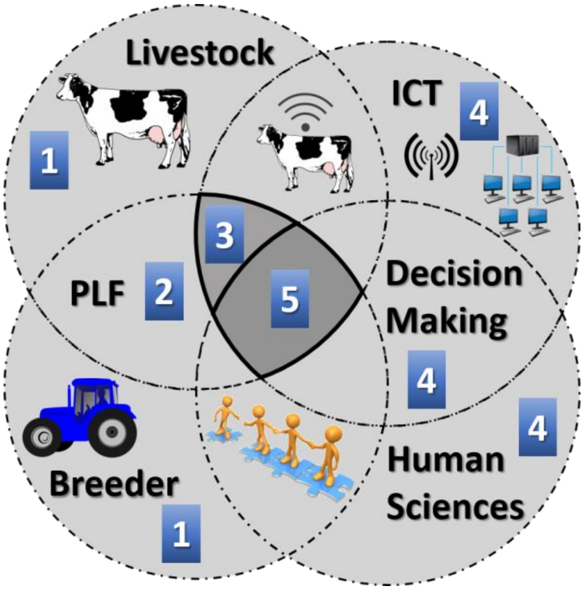

Figure 4. Smart Interfaces in a transdisciplinary project.

Contrary to classical thinking and as it has been said before, users (Label 1 in Figure 4) must be integrated the earliest as possible in the innovation project (Label 2 in Figure 4). This is the starting point.

Smart interfaces can be defined from two complementary and inseparable points of view. Firstly, the interface considered as the main contribution of the project: technological product or system (Label 3 in the Figure 4). Secondly, the interface considered as the transdisciplinary innovating process (Labels 4 and 5 in the Figure 4) [15]. In other words, to overcome the different issues analyzed in this paper, it is necessary that researchers and designers work together along with an integration of users in their reflections. Working together is not easy for people who are specialists in a precise field because everyone has his own logic. To work together, a decompartmentalization of scientific disciplines is mandatory, as well as an open-mindedness of researchers and the respect for different thinking. Consequently, it is imperative to exchange throughout the project to better understand each other. The result of this work is a trade-off between the expectations of the different stakeholders [16].

ACKNOWLEDGMENT

The work presented in this paper has been developed in the frame of the e-Pasto project (pilot project of AGRIPIR), which has been financially supported by the European Commission in the frame of the Spain-France-Andorra Territorial Cooperation Operational Program (POCTEFA 2007-2013) and the FEDER funds.

REFERENCES

[1] F. Bocquier et al., “Elevage de précision en systèmes d’élevage peu intensifiés [Precision farming in extensive livestock systems],” INRA Productions Animales, pp. 101-112, vol. 27, 2014.

[2] T-M. Banhazi et al., “Precision Livestock Farming: an international review of scientific and commercial aspects,” International Journal of Agricultural and Biological Engineering (IJABE), pp. 1-7, vol. 5, no. 3, 2012.

[3] L. Ruiz-Garcia, L. Lunadei, P. Barreiro, and J-I. Robla, “A Review of Wireless Sensor Technologies and Applications in Agriculture and Food Industry: State of the Art and Current Trends,” Sensors, pp. 4728-4750, vol. 9, 2009.

[4] D-D. Brown, R. Kays, M. Wikelski, R. Wilson, and A-P. Klimley, “Observing the unwatchable through acceleration logging of animal behavior,” Animal Biotelemetry, pp. 1-20, 2013.

[5] D. M. Anderson, “Virtual fencing-past, present and future,” The Rangeland Journal, pp. 65-78, vol. 26, 2007.

[6] A. Llaria, G. Terrasson, H. Arregui, and A. Hacala, “Geolocation and monitoring platform for extensive farming in mountain pastures,” Proc. IEEE International Conference on Industrial Technology (ICIT 15), March 2015, pp. 2420-2425.

[7] G. Terrasson, A. Llaria, A. Marra, and S. Voaden, “Accelerometer based solution for precision livestock farming: geolocation enhancement and animal activity identification,” IOP Conference Series: Materials Science and Engineering, pp. 1-5, vol. 138, no. 1, 2016.

[8] A. Aamodt and E. Plaza, “Case-based reasoning: foundational issues, methodological variations, and system approaches,” Artificial Intelligence Communications, IOS Press, pp. 39-59, vol. 7, no. 1, 1994.

[9] R. Dechter, “Constraint processing,” Morgan Kaufmann Publishers, Inc., 2003, ISBN 1-55860-890-7.

[10] F. Jensen and T. Nielsen, “Bayesian Networks and Decision Graphs,” Information Science and Statistics, Springer, 2007.

[11] E. Villeneuve, C. Béler, F. Pérès, L. Geneste, and E. Reubrez, “Decision-Support Methodology to Assess Risk in End-of-Life Management of Complex Systems,”. (In Press: 2016) IEEE Systems Journal. pp. 1-10, ISSN: 1932-8184.

[12] D.J. Panell, “Social and economic challenges in the development of complex farming systems,” Agroforestry Systems, pp. 393-409, vol. 45, 1999.

[13] V. Pilnière and C. Merlo, “Une approche transdisciplinaire et systémique pour favoriser le changement dans l'entreprise [A transdisciplinary and systemic approach to promote changes in the enterprises],” International Journal of Projectics, pp. 63-73, vol. 7, no. 1, 2011, ISSN: 2031-9703, ISBN: 9782804165222.

[14] C. Merlo and V. Pilnière, “Analyse des situations de travail dans une démarche de prévention des risques professionnels: proposition d’une méthodologie d’apprentissage à destination des acteurs [Analysis of work situations for the prevention of occupational risks: proposal of a learning methodology oriented to the involved actors],” 84th ACFAS Conference, May 2016.

[15] E. Morin, “Quelle Université pour demain ? Vers une évolution transdisciplinaire de l'Université [What University for tomorow? Towards a transdisciplinary evolution of the University],” Motivation, no. 24, 1997.

[16] C. Merlo and V. Pilnière, “Intervention conjointe SPI-SHS au service de la performance d’une organisation de soins à domicile [Combined application of Engineering Sciences and Social and Human Sciences for the performance of a home care organization],” ProjecticSanté, Oct. 2015.