Precision Livestock Farming Applications for Grazing Animals

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Precision Livestock Farming refers to the real-time continuous monitoring and control systems using sensors and computer algorithms for early problem detection, while simultaneously increasing producer awareness concerning individual animal needs. These technologies include automatic weighing systems, Radio Frequency Identification (RFID) sensors for individual animal detection and behaviour monitoring, body temperature monitoring, geographic information systems (GIS) for pasture evaluation and optimization, unmanned aerial vehicles (UAVs) for herd management, and virtual fencing for herd and grazing management.

Keywords: precision livestock farming ; grazing animals ; technology ; sensors

1. Introduction

The need for the improved quantity and higher quality of animal products, especially in developing countries [1], has led to the increase in size of animal herds, whereas the number of farmers has declined [2][3][4] and the availability of grasslands has been reduced because of cropping [1]. As a result, farmers have less time to assess individual animal needs and the grazing animal's feed resources are shrinking, resulting in welfare impairment [5][6] and health-related and performance concerns [7]. Precision Livestock Farming (PLF) techniques have shown great potential in solving such problems, since they represent a unique opportunity to convert herd management from manual to automated or semi-automated systems. They can potentially contribute to an amelioration of health and welfare status, minimize of on-farm labour and veterinary costs, improve farm waste management, and increase environmental and economical sustainability [8][9][10][11][12][13][14].

Grazing land represents 60% of the world's agricultural land, and is used by nearly 360 million cattle and over 600 million sheep and goats [15]. Grazing animals represent 10% of beef and about 30% of sheep and goat meat consumption globally [15]. Furthermore, it is estimated that grazing animals are the only source of livestock for over 200 million people [15]. A major advantage of grazing animals is that they utilize by-products that otherwise would be wasted, improve the diversity of grasses by dispersing seeds with their hooves, and ensure soil health with their manure. In addition, as the animals trample the soil, they break up the crust and increase the stimulation of grass growth and soil regeneration [15]. However, many of the world's grazing areas are threatened, as policies are contributing to the conversion of pasture into cropland. When the land is exhausted and returned to fallow, it does not revert to good pasture and, therefore, it is deserted. Thus, optimal utilization of the lands through improved grazing techniques where the animals continuously change allocated areas can lead to more sustainable farming and grazing systems [1][16].

PLF systems focus on managing any variable that interferes with the production process and trigger a series of alarm signals whenever a problem is detected [4]. The animals will express their discomfort due to lack of feed or undesirable environmental conditions, using bio-responses (i.e., changes in behaviour) that the system detects. Therefore, the first step in creating a PLF model is behavioural analysis through animal-based observations [17]. The development and analysis of large behavioural datasets produce models and algorithms that will be used as the "golden rule"—code for the automatic classification and identification process [9][18]. Detected behavioural changes will be automatically classified by the controller as normal or non-normal according to the behavioural pattern of best fit. After the classification process, the system's output will either assess the problem automatically or produce a series of alarm signals and provide possible suggestions, assisting the farmer in the decision-making process [19]. The bio-responses analysis may include both steady-state and dynamic component modelling methods [20]. Therefore, the resulting model should include at least one relationship between the variable of interest and the behaviour, and it should be able to predict future behaviour from previously recorded data. The comparison between the predicted and the actual measured behaviour (i.e., prediction error) will indicate if the animals' status has changed [4]. This information is used as an input for the controller in making the necessary adjustments to return the animals to their “normal state”. In other words, the animals’ bio-responses are used as indicators for the system and, in a sense, they represent the feedback sensor in a closed-loop control system [7].

2. PLF in Grazing Cattle

The average milk and dairy consumption has been constantly increasing over the past four decades, and it is expected that by 2050 it will increase by 50% compared with that of 2010 [21]. The increase in animal numbers per herd and the introduction of the high milk yield breeds of cows in the production process during the past century improved yield, while the farmers’ ability to assess individual animal needs decreased [7][22][23]. Therefore, the relationship between animals and humans, animal health and welfare status along with the consumers’ increasing need for food safety in quality products and the units’ sustainability are production elements that have been affected [23]. PLF technologies have demonstrated great potential in assessing or even solving these problems. The farmer can monitor the animals’ everyday lives noninvasively, no matter the size of the herd, and assess farming practices from their computer [23][24]. Therefore, PLF systems can potentially improve the animals’ well-being, enhance soil health, pasture utilization and management, while simultaneously improving animal performance (i.e., quality and quantity of the end-product) and enhance farmers’ annual income.

Various PLF technologies have been developed for grazing cattle, including RFID tags, boluses, collars, and noseband sensors for grazing behaviour measurement [25], in addition to monitoring cardiovascular and respiratory patterns (i.e., heart and breathing rates and oxygen saturation) for health and welfare assessment [26]. Ear tags and injectable glass tags are used for individual identification [27][28][29], individual data documentation (e.g., maternal pedigree), and disease trajectory monitoring [30]. Other PLF systems are walk-over-weight platforms and electronic scales, thermal analysis systems for body temperature assessment, camera analysis models for position detection and methane emissions estimation [31], sound analysis systems for rumination classification and analysis [32], video analysis for early disease detection, behavioural patterns classification and mating behaviour [33], GPS, GIS and accelerometers for individual animal location detection, theft prevention, feeding and ruminating behaviour detection [34], feed intake and reproduction monitoring [35]. It should be noted that PLF applications as such collect large amounts of data depending on the sensor type used and therefore large storage devices are mandatory. However, Bhargava et al. [36] presented a useful method to overcome this issue by using Wireless Sensor Networks combined with Edge Mining for data compression, memory usage optimization, and assessing future real-time PLF application models. However, internet access in most farms in the Mediterranean is limited; therefore, a LAN-based system could be more useful.

3. PLF in Small Ruminants

Extensive grazing-based systems are of particular interest for small ruminants, since they require low input costs and offer improved resilience against market fluctuations. Sheep and/or goat farms are often of small scale and their owners are generally conservative, and reserved towards new technologies, parameters that hinder the adoption of PLF on a regular basis within the production process [37], although variations exist around the world (e.g., Mediterranean dairy farms versus meat production systems in Australia or New Zealand). Moreover, poor technological infrastructure (e.g., electricity, telephone, and internet networks) and other financial barriers also limit PLF’s regular use [38].

Various PLF technologies have been developed over the previous decades in pasture-based farming systems of small ruminants (**Figure 1**). Electronic identification (EID) systems, such as ear tags, ruminal boluses, and subcutaneous transponders are the applications that are more frequently used, since they are mandatory in the European Union (EU). Innovative technologies that simplify flock management based on on-animal sensors are also employed and include global positioning systems (GPS), accelerometers, gyroscopes and social activity loggers that can provide data regarding several behavioural parameters, health, and welfare status. Furthermore, robots that identify wildlife and classify it as dangerous (i.e., predators) or harmless for added herd protection are under development. Finally, there are also other commercially available management systems that assist farmers, namely virtual fencing, flock monitoring using drones, and image analysis techniques, automatic weight monitoring using walk-over-weighing, or weighting crates and other milking parlour-related technologies [35][38].

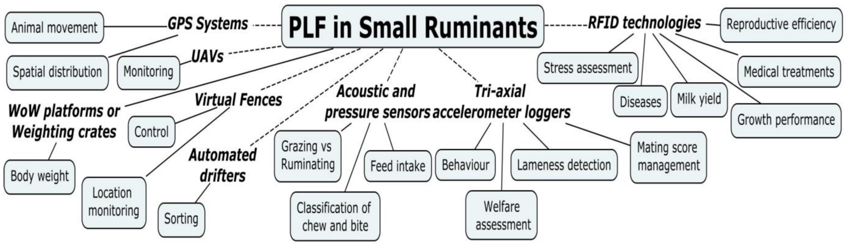

Figure 1. PLF applications in grazing sheep and goats.

4. PLF in Other Species

4.1. Pigs

Extensively housed (i.e., semi-free and free-range) pigs provide meat products of high quality that generally enjoy increased prices in the market [39][40]. Due to the nature of the managerial techniques and the limited number of extensive pig farms, there has been little commercial demand for implementation of PLF in this sector [40]. However, PLF technologies could be proved beneficial, as they provide security against theft, wildlife [41] and records concerning animals' health status and overall performance [7]. Furthermore, PLF could positively affect breeding, fattening performance and health status through monitoring and control, and strengthen consumer confidence by collecting data that refer to the characteristics of both the animal and farm [2]. Some PLF applications for free-ranging pigs are presented in the next paragraph.

Alexy and Horváth [40] presented results from the development of a continuous monitoring PLF tool for sows of the Mangalica breed that were extensively housed on a total area of 2.5 ha. RFID ear tags were attached to each sow and a monitoring area was designated. The extensive breeding site consisted of a tank drinker, a wooden feeder, the wallowing area (mostly created by the sows themselves), a wooden building used by the sows for resting, and five individual farrowing cottages. Four reading units were installed on a fence close to the wallowing area. A weather station recorded the climate data on an hourly basis. The system successfully recorded the hourly activity of the sows. They reported that the environment and the weather affected the activity of the wallowing site, as the sows tended to use it most in a temperature range between 0 to 4°C. Furthermore, it was stated that this particular activity was strongly connected with the animals' welfare status. With regard to social behaviour, the sows tended to create small groups that visited and left the wallowing site simultaneously. However, the system's evaluation parameters such as accuracy, precision, specificity, or efficiency were not provided. The researchers stated that additional reading units need to be installed in the pasture area and that additional sows will be marked with RFID ear tags. Aubé et al. [42] used hand-controlled video cameras and recorded and analysed sows' posture (i.e., standing, sitting, kneeling or lying) and activity (i.e., grazing, rooting or any other behaviour). Furthermore, a GPS receiver was fixed between each sow's shoulders and an accelerometer was installed on the lower part of one back leg for general activity assessment. An open-source geographic information system was used for GPS data processing, and they managed to successfully record frequency, duration, and the location of the foraging and resting behaviors of the sows, time spent on the pasture, and distance travelled. The authors reported that the applied method in their study was firstly used by Ringgenberg et al. [43], implying that simple systems used for indoor housing can potentially be used for free ranging animals. Van Damme et al. [44] used GPS receivers and successfully (p = 0.014) monitored the foraging and exploratory behaviours of free roaming pigs in Zambia. It should be noted that in both studies the authors only addressed the animal behaviour point of view and no PLF evaluation parameters for the systems were provided.

4.2. Poultry

In January 2012, the European Union issued the Council Directive 1999/74/EC banning battery cages for egg production in the poultry sector. By 2019, hens housed in alternative systems including floor, aviary, free-range and organic reached 50% of their total population in Europe, as indicated by the European Commission Eggs Market Situation Dashboard. Such systems provide additional behavioural freedom for the everyday activities of poultry, resulting in improved welfare status [45][46]. Furthermore, it has been reported that free-range laying hens demonstrate improved plumage condition, final body weight and egg weight compared with their counterparts that are housed indoors [45][46][47][48][49]. It should be noted that even after switching to non-cage systems, welfare challenges such as keel bone damage [50] and damaging behaviours such as feather, toe and vent/cloacal pecking and cannibalism still persist [46][51][52][53]. Furthermore, in free range systems, the higher exposure to parasites, pathogens and predation contribute to poultry welfare impairment [49][54]. Wild animals can cause severe damage in free ranging systems. For example, red foxes, which are a common predator of chickens, can eliminate the whole flock within a single night, resulting in severe losses [55]. PLF technologies could potentially minimize these negative effects and improve welfare and performance status.

As reported by Rowe et al. [56], more than 42% of the PLF systems use image analysis to assess welfare in poultry. This phenomenon is mainly attributed to the fact that image and video analysis and processing are inexpensive ways to record and analyse the behaviour of the birds without disturbing them [46]. Similarly, Campbell et al. [57] used a series of cameras to capture the indoor rearing pens and range area of each pen, and successfully classified the dust bathing and foraging behaviours, as well as the time the birds spent interacting with enrichment materials and the time the chicks spent expressing play behaviours with each other. Unfortunately, no information concerning the precision, efficiency, accuracy, or specificity of the system was provided. Montalcini et al. [58] developed a combined camera-based and RFID tracking system that automatically monitors individual bird movement over long periods of time for free-ranging commercial farms with an accuracy of 99%. The system overestimated the number of transitions carried out by the birds per zone (i.e., three stacked tiers of a commercial aviary, a littered floor and the winter garden), explaining only 23% of the actual variation, hence further research is needed to improve the performance of this application. Various camera-based methods can be found in the literature including wildlife interactions with free-ranging ducks [59] and chickens [60][61], activity [62][63] and ranging behaviour [64][65][66] monitoring, counting, or detecting of dead chickens [67], weight estimation [68], shelter preference behaviour monitoring [69], enrichment utilization monitoring [70], and meat colour and quality classification [71][72]. All of the methods are still under development and therefore further research is needed for the development of a commercial application.

Another widely spread PLF application in poultry is RFID systems. A variety of different sizes and settings have been developed, and they are available for commercial use, focusing on individual behaviour recording [73][74][75], feed intake monitoring [76], individual range use [74][77][78][79][80][81], range behaviour tracking [48][57][82][83][84], response to stressors monitoring [85], welfare assessment [86], range behaviour and health status evaluation [87], individual identification [88], individual movement parameters monitoring such as speed, ability to snatch feed and resting behaviour for disease detection [89], body weight, feed intake, egg production and quality evaluation [90], behavioural preferences, and indoor and outdoor resource utilization monitoring [80][91]. It should be noted that an alternative system to RFID technology consisting of a small, light-based monitoring system was developed by Buijs et al. [92]. The system demonstrated 89% or better accuracy for hens' position detection. Hedman et al. [93] developed a GPS-based system for individual chickens' position and movement monitoring but did not provide any PLF evaluation parameters. Finally, Stadig et al. [94] developed an automated Ultra-Wideband positioning system for location monitoring with an accuracy of 68%. Further research is needed for the improvement of the system's internal characteristics and accuracy.

More complex systems have been introduced during the previous decade, including automatic egg collection robots [95][96], behaviour monitoring [97], dead chicken removal robots [98], and guardian dog monitoring using a combination of GPS and camera equipment for auto-guidance for the repulsion of wildlife such as red foxes [55]. Gilsdorf et al. [41] also reviewed a variety of different technologies concerning the use of frightening devices for wildlife repulsion and therefore wildlife damage management. They reported that today's ultrasonic devices are ineffective at repelling birds and mammals. However, the potential of a combination of frightening devices could provide a cost-effective integrated system that considerably reduces wildlife damage. However, only a few commercial applications have been released due to their complexity and limited field testing. Furthermore, a thorough economic analysis for the systems' total costs is essential for the development of commercial products [4].

5. Conclusions

The constantly increasing global need for higher quality food and improved animal welfare status based on sustainable farming systems highlights the necessity of high-quality livestock management. PLF technologies have shown great potential in addressing this issue in an animal-friendly manner, while simultaneously providing the farmers with information that further assists them in decision making. The application of such technologies is directed towards the automatization of simple procedures, the minimization of labour and environmental impact, and the improvement of animal welfare. PLF applications can only serve as decision making support tools for farmers, since automatic decisions for efficient handling and critical health and welfare issues are not feasible at present. Furthermore, although various PLF applications for grazing animals are available commercially, their use is limited and can be found mainly in cattle production rather than in small ruminants or other species. This is likely attributed to individual animal value and producers' reluctance due to financial constraints, unresolved welfare concerns, lack of specialized nearby service, and complexity in using the technologies. The limited testing and the lack of cost-benefit evaluation make these technologies undesirable for farmers. Future PLF research should focus on improving the systems' evaluation parameters and should be based on realistic and thorough economic analysis, emphasizing their beneficial impact. In parallel, ″friendly″ software and effective marketing techniques should be applied to persuade more farmers to adopt the technologies.

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