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# Contribution of Precision Livestock Farming Systems to the Improvement of Welfare Status and Productivity of Dairy Animals

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**Abstract:** Although the effects of human–dairy cattle interaction have been extensively examined, data concerning small ruminants are scarce. The present review article aims at highlighting the effects of management practices on the productivity, physiology and behaviour of dairy animals. In general, aversive handling is associated with a milk yield reduction and welfare impairment. Precision livestock farming systems have therefore been applied and have rapidly changed the management process with the introduction of technological and computer innovations that contribute to the minimization of animal disturbances, the promotion of good practices and the maintenance of cattle's welfare status and milk production and farms' sustainability and competitiveness at high levels. However, although dairy farmers acknowledge the advantages deriving from the application of precision livestock farming advancements, a reluctance concerning their regular application to small ruminants is observed, due to economic and cultural constraints and poor technological infrastructures. As a result, targeted intervention training programmes are also necessary in order to improve the efficacy and efficiency of handling, especially of small ruminants.

**Keywords:** small ruminants; aversive handling; precision livestock farming systems; animal welfare; milk production

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## 1. Introduction

The demand for dairy products is constantly increased as a result of the world population increment, which is expected to rise from 7.7 billion in 2019 to 9.7 billion by the year 2050 [1]. Over the previous decades, intensive farming systems have been extensively applied in order to cover consumers' needs and requirements. Although dairy farms around the world are growing in size due to the rising costs and additional benefits of economies of scale, the husbandry staff to animal ratio is decreasing [2]. On the other hand, milk yield and quality requirements are constantly rising (i.e., lower accepted somatic cell thresholds), resulting in higher energy demands per kg of milk and less time for the farmer to spend with individual animals [3–5]. This intensification is often related to group-oriented husbandry practices, due to limited capital and labour availability, which could lead to the poor management and impairment of animals' well-being, resulting in a diminished productivity and competence of units [6]. Although, the herd size cannot be considered a feasible indicator of the on-farm animal welfare level [7], other parameters that could be affected by the herd size such as the health status and water accessibility could negatively affect the welfare status [8]. Approximately 20% of the milk yield is lost due to improper management, and appropriate practices are necessary for the attainment of high productivity and welfare levels [9]. As it can be concluded, an improved welfare status and appropriate management practices are strongly related with the efficiency and efficacy of dairy systems [10]. However, it is important to point out that increased productivity is not necessarily associated with high levels of welfare. An improved health status, a normal growth performance and reproductive function, and high milk yield levels could be considered sound indicators of improved animal welfare; however, there are also other parameters that probably integrate both the health status and productivity of farm animals, such as their longevity and display of natural behaviours [11].

Although a high productivity is generally associated with an increased yield and improved quality of the derived milk, dairy animal welfare is a complex concept that combines the mental and physical aspects of the animal and is not similarly defined and perceived around the world [12]. Welfare can be defined as the state of harmony between an individual and its environment, and it is based on the adequacy of the individual to cope with its environment [13]. Any observed divergence from this equilibrium, if perceived by the individual, causes a welfare deficit due to negative emotional experiences [14]. Most of the examined quantifiable welfare indicators currently refer to negative aspects—such as high levels of stress hormones (i.e., corticosteroids, cortisol and prostaglandins); abnormal behaviours (i.e., stereotypes, tongue rolling, cross-sucking, urine licking and wool eating); aggressiveness; fear (i.e., ears pinned back or wide-eyed animals); diseases and lameness—since a deficit of knowledge exists regarding the valid interpretation of the mental state of animals [15]. However, it is generally accepted that welfare is fulfilled when animals experience positive emotions and do not remain in a negative emotional status for a prolonged period [14]. This recognition has recently contributed to the consideration of the concepts of 'animal happiness' and 'a life worth living', where the emphasis has shifted from negative to positive aspects of animal welfare [16]. Fraser [17] categorized the main scientific approaches that are used for the definition of animal welfare into three groups, based either on: the physiological functions of the animals (objective); the emotions and mood experienced by them (subjective), ranging from depression to pleasure; or the similarity of the rearing conditions to their natural state (natural living/naturalness). Dairy animals should be provided with a range of stimuli that offer freedom (the 'Five Freedoms' paradigm), comfort, pleasure, interest and confidence—in other words, positive affective engagement—according to the four welfare quality principles: adequate nutrition; adequate housing (environment, healthy animals); normal biological functioning and fitness; and normal behaviour display (a mental state that safeguards a high welfare status within the proper constraints of an effective dairy farm) [16,18,19].

Interactions between handlers and lactating animals—such as dairy cattle, buffaloes, sheep and goats—are frequent, as conventional milking is usually performed more than once daily and still plays a very important role in affecting animals' performance and welfare status [20,21]. A farmer's intention should be to perform effective handling with minimal discomfort and stress for the dairy animals, which is achieved through pats, gentling, quiet movements and respect of animals' flight zone, since negative treatment generally impairs not only their growth development, reproductive performance and milk yield and quality, but also their health and welfare status [10,20,22,23]. Aversive handling is associated with improper management practices, and stressors such as shouting, pushes, slaps and hits, quick or unpredictable movements and the unnecessary utilization of electric prods can induce fear in animals, leading to an undesirable emotional state of suffering [10,20]. Fearful animals display increased levels of restlessness, observed as a high frequency of stepping and kicking and in their regular inspections and handling being strenuous and requiring more time, posing a risk to both human and animal safety [24]. Acute stress during milking can dramatically reduce the milk yield, due to an inhibition of the milk letdown through the secretion of catecholamines at the expense of oxytocin, leading to an impairment of milk ejection [25,26]. At the same time, continuous elevations of corticosteroids negatively affect the protein metabolism and hypothalamic–pituitary–adrenal (HPA) axis activation, leading to the release of pro-inflammatory cytokines [27].

Precision livestock farming (PLF) technologies have been developed with the intention to improve farm management and minimize aversive handling practices. According to Berckmans [28], a PLF system: (a) is a support tool that includes cameras, microphones and other sensors for tracking livestock, as well as computer software, and could improve the production efficiency through the adoption of electronic data collection, processing and application, but does not intend to replace the farmer; (b) is an animal-centric tool—the animal is the main part of the process; and (c) needs ideal conditions for the monitoring and control processes. For example, PLF systems have revolutionized the milking process through the introduction of automatic milking robots, leading to an improved quality and increased quantity of milk, while welfare status is maintained at high levels [29], since each individual animal can choose their preferred time of being milked [30]. PLF are real-time monitoring technologies with the core purpose to 'manage even the slightest manageable production unit's temporal variability (i.e., per animal approach)' [31,32]. They are frequently integrated with other new technologies in order to improve the human–livestock interactions, productivity and economical sustainability of modern farms [33]. In early years, milking robot machines were mostly used for indoor farming. However, automatic milking systems could also be applied in semi-grazing and pasture-grazing farms [34,35].

Nowadays, consumers' concerns about the implications of mass-production systems on the welfare of dairy animals are continuously increasing, despite the fact that their level of knowledge about animal welfare issues, housing conditions and farm management is low [36]. According to the 'Farm to Fork Strategy' [37], farming activities are no longer perceived solely as food production systems, but are fundamental to safeguarding other concepts, such as food safety and quality, environmental protection and sustainability [38]. 'Social license' refers to the ongoing acceptance of farm practices and operating procedures by the general public and community [36] and is of vital importance for the continued support of dairy farms. Animal welfare parameters are increasingly affecting purchasers' choices, since welfare is considered a primal attribute of the food quality concept and animal-friendly products are nowadays considered safer, tastier, healthier, authentic, environmentally friendly and traditional by many consumers [38].

To meet community demands, targeted cognitive–behavioural training programs and specific protocols aimed at the handling improvement are therefore necessary in dairy farms in order to maintain an improved welfare status and production efficiency [39]. Undoubtedly, the attitudes and skills of the farmer and his/her familiarity with the animals are very important; however, there are also issues—such as job satisfaction and motivation, working conditions and organisational policies and rules—that modify handling practices [20,24]. As indicated, participation in a training program focusing on handling and management reduces the probability of animals having their tails clamped, ears pinned back or being wide-eyed during the milking procedure [40]. That dairy products originate from improved welfare conditions can be further communicated to consumers by associated labelling and certification schemes, resulting in additional profit and possibly increased market share [36]. An internationally accepted, transparent and traceable monitoring system is therefore necessary for the promotion of welfare-friendly products and the maintenance of dairy farming's 'social license' through the public's credibility and approval [36]. As indicated, younger consumers are more willing to pay for welfare-friendly products, and this fact is very important, since they will be the main formers of the food market in the future [36].

The aim of the present article is to review the existing literature concerning the interaction of the farmer with the most important dairy species, such as dairy cattle, buffaloes, sheep and goats, and its effects on their welfare, health and productivity. At the same time, the contribution of precision livestock farming systems in improving several aspects of ruminants' performance and well-being are evaluated.

## 2. Human–Dairy Animal Interaction

### *2.1. Dairy Cattle and Buffaloes*

The human–dairy cattle interaction and its effects on milk production and welfare status have been extensively examined [10,20,22,39]. Aversive handling and forceful, negative tactile interactions are generally associated with fear, high signs of nervousness, a reluctance to move to the milking parlour, baulking, an increased number of vocalizations or steps [10,20,22], a decreased proportion of conceiving to the first insemination [20], a reduction of the milk yield and a deterioration of the milk quality (i.e., reduced protein and fat levels) [10,20] in dairy cows. At the same time, aversively treated cows are more fearful of people and more difficult to handle, due to the increased secretion of cortisol and catecholamine as a result of excessive hypothalamo–pituitary–adrenal and sympathetic nervous system activity, respectively [24]. The high rates of agitation are assessed as an increased number of flinch, step and kick responses during milking process [10,41]. The ease of handling is affected by the nature of the human handling, and the response may be extended to other humans through the process of stimulus generalization [42].

The flight distance, defined as the distance to which an animal allows a moving person to approach, is also positively correlated with negative interactions at a moderate level [20,43]. Cows rapidly learn to avoid milkers associated with aversive handling, but this clear avoidance response may not indicate a level of fearfulness that negatively influences milk production [41]. As indicated, the flight or approach distance is in general not correlated with milk production [44]. Shouting and the utilization of electric prods appears to have the most intense aversion effects on the behaviour expressed by dairy cows, as cows needed more time and required more force to walk down an experimental race [45]. It is noteworthy also that non-producing periods, before maturity and during the dry period, play a very important role in the subsequent and lifelong advantages of a good relationship between the stockperson and dairy cows [46]. In addition, a positive farmer attitude towards his/her cows contributes to decreased rates of forceful and negative tactile interactions and an improved level of welfare [10,20,24,43].

On the other hand, gently handled animals show a decreased avoidance of people [47] and improved fertility rates and udder health [20,48]. Furthermore, positive interactions (gentle touching, talking quietly, petting etc.) between the milker and dairy cattle result in a reduced display of kicking and stepping [49], which is associated with efficient handling [50], decreased heart rates [51] and milk cortisol levels [49] and an increased milk yield [52]. Pre-partum strategies result in a familiarization with the milking parlour and improve the welfare status of dairy cattle [53]. For example, stroking in certain areas, particularly the neck, decreases the display of avoidance behaviour and increases the approach behaviour of dairy cattle, providing evidence that positive tactile interactions with humans can make a positive impact on routine handling procedures [54,55]. This is more evident at earlier age, since a positive affiliative interaction with the caretaker leads to calmer dairy cattle in later life [47,56]. Becker and Lobato [57] reached to the conclusion that short daily positive interactions could improve the ease of handling of Zebu crossed (Nelore x European) calves that are considered to have a more difficult temperament, leading to a reduction in labour costs and injuries.

Apart from human–animal interaction, genetic factors such as a breed's temperament could also affect cows' physiological and behavioural responses to milking, resulting in discrepancies both between and within breeds [58,59]. However, the subjection of nervous cows to pleasant treatment such as stroking and brushing at an early age could minimize stress responses displayed during milking, leading to an increase in the milk-flow rate and a decrease in the milking duration [40,60]. Moreover, dairy cattle that interact less frequently with humans have increased rates of 'flinch, step, kick' responses associated with a nervous milking temperament and are overall more difficult to handle compared to cows that are handled more often [61]. Even mild to non-detectable stressors such as an unfamiliar environment could induce increases in the vocalizations, heart rate and cortisol levels of dairy cattle [62].

Negative human–animal interaction during milking is positively correlated with kicking and restless stepping also in dairy buffaloes (with a correlation coefficient within 0.58 and 0.94) [63,64]. Buffaloes are more sensitive to stress stimuli than dairy cattle during milking, due to that fact that they are less intensively selected and domesticated compared to dairy cattle. At the same time, they are very consistent in their milking routine; therefore, even slight changes can influence their behaviour and performance during their milking [65]. As a result of stress, a secretion of adrenaline is induced, leading to a decrease in the oxytocin supply through vasoconstriction or the blockage of oxytocin receptors found on the myoepithelial cells of the udder alveoli, which is strongly associated with a reduced milk production [66]. On the other hand, positive interaction results in an improved milk production in dairy buffaloes [64,67]. The nervous temperament of buffaloes during milking could further lead to a reduced milk yield and fat content [68]. As indicated, the pre-partum habituation of buffalo heifers to the milking procedure reduces the level of restlessness, since fewer steps and kicks are observed during their milking compared to the control animals [67].

### *2.2. Small Ruminants*

Scarce data exist on the effects of human–animal interaction on the productivity and welfare of sheep and goats. Aversive handling (slaps, pushes and loud shouting) leads to a reduction of the milk yield and an increase in kick responses during the milking of dairy ewes, although the milk flow rate was not affected [69]. Goats receiving aversive handling also showed increased salivary cortisol levels [70]. On the other hand, the development of a positive human–animal relationship results in ewes that are calmer and less reactive to the milking routine, with an improved welfare, more effective milk ejection and increased production [71]. Positive tactile interaction has been shown to improve the health status and increased heart girth of dairy goats and reduce their levels of stress [72]. In general, gentled animals show reduced flight distances, heart rates and cortisol levels in the presence of humans [73,74]. A positive affiliative bond with the caretaker during the early stages of life in lambs leads to positive behavioural and physiological consequences and calmer animals at adolescence [75–77].

In contrast, no differences in the milk yield, milk quality and kick number during milking were observed between ewes classified as nervous or calm based on their temperament, although nervous ewes were less reluctant to enter the milking parlour, and the attachment of the milking cups to them took a longer time than it did to the calm ewes [78]. Furthermore, Napolitano et al. [79] observed that the positive attitude of a farmer towards their sheep resulted in positive interactions and was negatively correlated with the flight distance in the pen.

## **3. Precision Livestock Farming (PLF) Advancements in Dairy Production**

### *3.1. Dairy Cattle*

PLF systems have been developed to assess the welfare and health status of dairy animals by reducing labour demands. In detail, they aim at the fully automated continuous monitoring of ruminants, emphasizing individuality, by utilizing technological and computer innovations as part of the production process. Sensing devices refer to almost any sensor that might be utilized and applied within any step of the production process (e.g., image and sound, temperature, pressure, blood and urine analysis sensors, etc.). PLF systems' function is mainly based on monitoring the animals' behaviours (e.g., feeding, drinking, lying, etc.) and behavioural changes due to external factors such as housing conditions (e.g., temperature and humidity variations and air flow), or biological changes (e.g., oestrus, calving and diseases) that greatly affect the animals' health and welfare status [80,81]. When such behavioural changes are detected, the system triggers a warning signal, enabling the farmer to take immediate action, and leading to an early problem diagnosis and solution or an immediate housing practices assessment [82,83]. At the same time, the farmer can monitor the animals' everyday lives irrespective of the size of the herd [5]. Therefore, the application of these systems can potentially improve animals' health and welfare, the quality and quantity of the end-product and enhance the economic viability of the unit.

Stygar et al. [84] reported that 129 commercial applications from 67 different providers are available in the dairy cattle industry today. These technologies include: milking robot; accelerometer-based sensors for monitoring the health status; load cell systems combined with radio-frequency identification (RFID) technologies (i.e., collar-, leg-, ear- and halter-mounted sensors) for rumination time recording, heat stress detection, movement tracking, individual identification and lameness detection; boluses used for body temperature monitoring, pH analysis, rumen activity and individual identification; complex camera-based systems for body temperature monitoring (i.e., thermal cameras), body condition scoring and monitoring feeding and drinking behaviour; GPS sensors for monitoring activity; sound analysis systems; and mobile applications for body condition scoring and weight estimation (Table 1). However, only 14% of the commercially available systems have been validated externally, undermining their credibility [84]. For example, false alerts of modern sensor technology could minimize the benefits stemming from PLF's application. The lack of validation and unfamiliarity of PLF technology are the main obstacles to dairy producers adopting these systems on farms.

**Table 1.** Application of precision livestock farming advancements in dairy cattle.

| Parameter of Interest | Applied Technology | Reference |
|---|---|---|
| Feeding | Precision concentrate rationing | [85] |
| Herd management | Wireless sensing | [86] |
| Oestrus detection | Pedometers<br>Animal-mounted detectors<br>Camera-based systems<br>Infrared sensors<br>Herd navigator | [87–90]<br>[91–97]<br>[97,98]<br>[99,100]<br>[101–103] |
| Lameness detection | Neural network models<br>Internet of things (IoT)<br>Mount detectors<br>Camera-based systems | [104]<br>[105,106]<br>[106–109]<br>[110–116] |
| Mastitis detection | Milk's electrical conductivity analysis sensors<br>Milk colour analysis sensors<br>Lactate dehyfrogenase analysis sensors<br>Various sensors installed on milking robot for measuring milk yield, body weight, lactose, fat and protein percentages, blood percentage and somatic cells counts<br>Infrared sensors and thermal cameras | [117,118]<br>[119]<br>[120]<br>[35,121–123]<br>[124,125] |
| Health status and behaviour | Various animal-mounted wireless sensors<br>Biometric sensors | [126]<br>[127,128] |
| Rumination and health status monitoring | Microphones<br>Accelerometers | [129,130]<br>[131,132] |
| Individual identification | Drones<br>Camera-based monitoring | [133]<br>[134–137] |
| Body weight and body condition score estimation | Camera-based monitoring<br>Ultrasonic sensors<br>Thermal cameras | [134–137]<br>[138]<br>[138–140] |

### 3.1.1. Assessment of Health Status

The most common health issues in the dairy industry are mastitis and lameness. The presence of these diseases can have a serious impact on a unit's everyday processes, damaging the health and welfare of the animals and the production quality and quantity—hence negatively affecting the economy of the unit [141]. The economic loss can be traced to a decreased milk yield [107,142,143], reduced reproductive performance [144,145] and increased culling risk [146]. A variety of PLF technologies have been introduced for the monitoring and early detection of such problems [4].

Lameness Detection

Lameness is among the top three health-related causes of economic loss in the dairy industry. Animals suffering from lameness demonstrate a reduced mobility, milk yield, reproductive ability and loss of body condition and feel intense pain [144]. To date, the diagnosis of the disease relies mostly on visual observation, which is time-consuming and sensitive to variations between the observers, and it is often omitted, resulting in production losses and increased treatment costs [147]. Therefore, it is essential to detect lameness at an early stage for effective treatment and disease progress prevention.

Several models have already been developed for lameness detection by monitoring individual animals' locomotion and walking patterns and have been proven to be very promising for assessing the problem. Pastel and Kujala [104] developed a four-balance probabilistic neural network model based on weekly measurements of the leg load (i.e., leg weight pressure) of 73 cows over a 5 month period. They reported a score of 100% lameness validation and 96.2% classification success. Viazzi et al. [111] developed a camera-based model that detects lameness by monitoring individual animals' locomotion and walking patterns. Using the population approach, they reported a correct classification score of 76%, 83% and 22% of true positive and false positive rate, respectively. However, when the individual monitoring approach was used, the classification accuracy was considerably increased by 10% (i.e., up to 91%) and the false positive rate was decreased to 6%, implying that individual monitoring is the most effective way to detect lameness compared with the population threshold. Romanini et al. [112] developed a model based on a 3D video data analysis, and successfully classified 75.7% of lameness cases with an accuracy of 91.3%. However, the level of misclassification of the systems led to multiple false alarm signals, and thus, further research is needed for the development of a commercial application. Thermal imaging can also be used as a diagnostic tool for the detection of temperature changes that are often related with an infection or inflammation of the hooves and lameness [148].

Mastitis Detection

Milking dairy cows has been a common process since at least 3100 BC, and bovine mastitis disease has probably existed since the same era [149]. However, a complete understanding of the disease only came alongside the invention of microscopes that allowed the detection and analysis of microorganisms, and Breed and Brew [150] first reported the existence of streptococci bacteria in milk. Since then, mastitis has become one of the most referenced research areas, emphasizing its effects on public health [149], the degradation of milk characteristics and milk quality [151], animal welfare deterioration [152] and mastitis' negative impact on the economy of units [153].

During the 21st century, technological advancements have allowed scientists to develop various models and PLF applications, improving animals' health and welfare and at the same time bringing the farmer closer to the individual animals [154]. Since milking robots' introduction in the managerial process of farms, a variety of automatic mastitis early detection systems have been developed [121]. These systems consist of at least two basic elements: (a) a combination of sensors for data collection and (b) the development of algorithmic models that translate the data into alerts alongside a decision support/making system [155]. The most common variables analysed and evaluated for the detection of mastitis include: milk's electrical conductivity [117,118]; milk's colour [119]; lactate dehydrogenase [120]; milk yield, body weight, lactose, fat and protein percentages; the blood percentage; and somatic cell counts (SCC) during automatic milking [121,123]. Furthermore, PLF technologies that are under development include infra-red and thermal cameras [124,125], biometric sensors (either invasive or non-invasive) for real-time individual health and behaviour monitoring [127]. Therefore, today's farmers can choose between a variety of systems to fit their individual needs, simplify their everyday processes, cut down their workloads, improve the welfare of their animals and increase the sustainability of their units.

### 3.2. Small Ruminants

Small ruminants are often managed as a flock/herd, allowing only average welfare states to be considered. Innovative technologies provide a unique opportunity to monitor and improve welfare management from the farm-level manual to automated or semi-automated assessment and management at an individual level, leading to a reduction along the value chain (https://techcare-project.eu, accessed on 7 September 2021) of on-farm labour and veterinary care costs [156]. However, PLF technologies and applications are not common in small ruminant farming, since most sheep and goat farmers' acceptance and adaptation of the new technologies remains considerably low, and most technologies and PLF applications are therefore mainly used for research purposes [33].Small ruminant farms are often located in remote and mountainous areas, where infrastructure and services are poorly developed. High equipment costs, a lack of demonstration and specific training and low education levels also contribute to the delay of PLF's implementation. At the same time, there are also practical issues related to the productive cycle of small ruminants that present a barrier to the application of PLF advancements. For example, although oestrus detection is of vital importance in dairy cattle and the main driver of PLF applications for cows, it is not such a priority for small ruminant farmers [80]. According to Wishart [157], PLF technologies would be more attractive to sheep and goat farmers if researchers focused on demonstrating the beneficial impact these systems have on welfare and efficiency, leading to more sustainable and profitable units. Table 2 presents PLF applications used in research for minimizing or even solving a variety of different problems in contemporary sheep and goat farms.

**Table 2.** Application of precision livestock farming advancements to sheep and goats.

| Parameter of Interest | Applied Technology | Reference |
|---|---|---|
| Grazing and ruminating behaviour | Animal-mounted accelerometer/gyroscope sensor<br>Animal-mounted tri-axial accelerometer loggers | [158]<br>[159] |
| Resting, grazing and searching behaviours | Animal-mounted tri-axial accelerometer loggers<br>GIS systems<br>Animal-mounted GPS sensors | [159]<br>[160]<br>[160–163] |
| Animal tracking | Animal-mounted GPS sensors<br>Animal-mounted tri-axial accelerometer loggers | [160–163]<br>[164] |
| Sexual behaviour of rams | Animal mounted accelerometers | [165] |
| Feeding behaviour | Camera-based analysis<br>Microphones<br>Animal-mounted gyroscopes<br>Animal-mounted accelerometers<br>GPS sensors | [161]<br>[161]<br>[161]<br>[161,166,167]<br>[168] |
| Oestrus detection | Alpha-D detector<br>Infrared thermography | [169,170]<br>[171,172] |
| Lameness detection | Infrared thermography<br>Hoof weigh crate with four load platforms | [173]<br>[174] |
| Lambing detection | Animal-mounted temperature sensors | [175] |
| Health status detection | Implanted sensors (heart rate and body temperature) | [176] |
| Individual identification | Injectable transponders<br>RFID sensors<br>Endoruminal bolus<br>Drones—image analysis | [177,178]<br>[156,179,180]<br>[180,181]<br>[182] |
| Age identification | Sound recorders analysis | [183] |
| Flock monitoring | Drones—image analysis | [182,184] |
| Weight monitoring | Automatic weigh-crates | [157] |
| Standing/lying behaviour monitoring | Camera-based analysis<br>Ultra-wide band real-time location<br>Animal mounted accelerometers | [185]<br>[185]<br>[186] in goats |
| Flock management | Virtual fence (i.e., animal-mounted collars embedded with electromagnetic transmitters and ground-installed receivers and sound speakers) | [187–192]; [193] in goats |

PLF's adoption in commercial applications is more common in intensive large-scale farms. Although several sensors, injectable devices, ear tags, rumen boluses, pedometers, collars and infrared cameras have been developed, the most common PLF application for sheep and goats is to install sensors in the milking parlour. According to Alejandro [194], the most ordinary automations applied to small ruminants include:

(a) Automatic vacuum shut-off (AVSO), which is a mechanism, either time- or flow-based, that prevents overmilking and its negative impact on the animals' health and welfare. Therefore, it improves the sanitary status of the milking parlour, while at the same time reducing the labour required. Bueso-Ródenas et al. [195] and Romero et al. [196] reported that the flow-based AVSO is better than manual milking, as the same amounts of milk were extracted in shorter time intervals. Furthermore, they proposed that the best combinations of the flow limit (i.e., the time interval during which the vacuum shut-off is activated) and delay time (i.e., the minimum flow set, such that below that point the vacuum shut-off is activated) for sheep are 150 g/min and 20 s or 200 g/min and 10 s, respectively, and that for goats it is 100–150 g/min and 10 s, respectively.
(b) Milk meter and flow indicators, which are sensors that allow the monitoring of the milk flow of every individual animal. Electronic milk meter measurements are based on the combined data of infrared and conductivity sensors and/or a volume measuring chamber [194]. The data is analysed and presented on the display of a personal computer. Furthermore, electronic milk meters have the ability to sample and analyse milk, providing information on the animals' health status [194,197]. Therefore, milk and flow meter applications are an essential decision-making tool for the farmer.
(c) Electronic identification assessment, which is performed by various sensor-based applications such as injectable transponders [177,178], RFID [156,179,180], endoruminal boluses [180,181] and drones [182]. These systems carry individual information concerning the age, weight, gender, health status and milk flow of every animal. The producer can keep a catalogue of all individual animals in the flock, and thus, they are a very useful long-term decision-making tool. It should be noted that to date mostly the RFID technology is used, as the transmitters attached on ear tags or foot are read from the receiver installed in the milking parlour and therefore the data flow can be accessed remotely in real time.
(d) Automatically operated sorting gate and weighing scale systems are connected to a flock management software, which sorts the animals into groups or modifies existing groups and separates the animals in need of treatment. These systems minimise both the labour and time spent regrouping and relocating the animals [194], practices that are commonly applied to obtain uniformity within groups in terms of milk yield [198].

Although small ruminant farmers acknowledge the advantages deriving from the application of PLF techniques, a resistance to their regular adoption due to economic and cultural constraints, poor technological infrastructures (electricity, telephone and internet networks) and a lack of information and competence is observed [80,199]. At the same time, sensor manufacturing companies are not interested in the development of sensors that can be used on small ruminants due their high device cost (miniaturization, decreased manufacturing numbers), the large number of animals per farm and the low individual profit compared to dairy cattle [80]. However, European agricultural policy that is affected by concepts such as climatic change, global warming, green economy, animal welfare and antibiotic resistance could influence farming practices and stimulate a wider adoption of PLF systems in the near future [33].

## 4. Conclusions

The existence of a correlation between handling, productivity and welfare in commercial dairy farms highlights the necessity of high-quality farm management. Precision livestock farming systems appear to provide an alternative, since they could serve as useful support tools for the farmer's decision making and improve the sustainability and competitiveness of dairy farms through the implementation of automated procedures that minimize the labour demand, animal disturbances and environmental impact. Sensor applications are expected to be continually developed with further advancements with regard to their size, energy management and data transmission protocols. The software used in PLF systems must not be complex and needs to be designed in a format that farmers and staff can easily understand, to predict risks over the short term and increase productivity and profitability in livestock over the long term. However, even with technological innovations that enable improved precision farming and automation, efficient handling is still fundamental to improving farm animals' welfare and its associated health and production benefits. Especially in small ruminants, PLF applications are still scarce, and training programs targeted at the improvement of daily routine practices are therefore necessary in order to sustain high welfare and production levels.

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