

Review Article

A Review of Sensor Technologies Applicable for Domestic Livestock Production and Health Management

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The world is running for the digitalization of social, economic, and political endeavors. As the world is getting into technologies of various streams of development, agriculture, especially livestock production, is also one of the areas of development that requires the application or use of emerging technologies. But knowledge and skill are relatively scanty, particularly in developing countries. Hence, it is vital to fill this gap of knowledge by compiling information and presenting it to a large audience for further research in the field. In the era of the advent of sensors for broader fields, it is important to consider the possible application of these technologies in rangeland condition assessment and animal production. The technologies are more relevant in the implementation of precision farming practices of livestock including the individual animal behavior, grazing condition, health condition, and forage intakes. For grazing stock, it is vital to assess the status of both livestock grazing behavior and rangeland resource conditions. The rangeland resources are important components of livestock production throughout the world. Forages and pasture are dynamics in the abundance, species composition, and chemical composition as a result of environmental and management changes. The rangeland resources must be assessed and monitored for better management and utilization. Conventional assessments which include manual or mechanical counting, identification, and chemical composition are laborious and time-consuming. Under field conditions, not only grazing lands condition can be monitored using sensors but also is possible to understand the grazing behavior of animals for better management of grazing stock. To complement and or replace conventional techniques, it is vital to understand the current technologies such as sensors or biosensors. This review study is organized to increase awareness of the available technologies and their relevance regarding rangeland resources, particularly in tropical rangelands. In most cases, in the tropics, GPS systems are commonly used to assess only the rangeland status without considering the grazing stock. The review also elucidates that sensor technologies are important to detect livestock health conditions and movements at the field level in a rapid and easy way. However, like other technologies, sensors (biosensors) have limitations including accuracy of measurements and repetitive data accusations. Nevertheless, the review elucidates the use of sensor technologies and saves time and energy in animal production which otherwise could demand extensive energy and time.

1. Introduction

In livestock production, animal health, availability of good quality, and adequate feed represent the highest proportion of production inputs. In many parts of the world, the major supplier of forages in herbivore animals is rangelands [1]. Grazing land resources support herbivores and are important for many people around the world who are directly or indirectly dependent on livestock [2]. However, the existing rangelands require proper management for optimum and sustainable use. The proper use of rangelands requires

adequate monitoring using appropriate technologies. There has been an interest in sustainable rangeland management over the last 20 years [3]. The forages grown should be managed well and assessed for yield and quality by using relatively cheap technologies. Of digital technologies, different sensor technologies are applied in agriculture to obtain precise agricultural information including optimization of crop production, livestock rearing, and adaptation of climate change regarding the farming activities [4]. Sensors or biosensors are analytical tools that change a biological reaction into an electrical signal. Essentially,

biosensors must be very precise, independent of physical parameters such as pH and temperature, and should be reusable [5]. The use of biosensors dates back to the 1960s by the pioneers Clark and Lyons in the detection and interpretation of reactions such as enzyme-based, tissue-based, immunosensors, deoxyribonucleic acid (DNA) biosensors, and thermal and piezoelectric biosensors. Similarly, a report by [6] showed that the advancement of technology continued innovation in sensor technology has created opportunities for monitoring of animal behavior. Knof and Bassi [7] stated that biosensor includes those types of equipment that help in the translation of biological intelligence to a measurable signal in the presence of an analyte.

The most commonly used sensors in agriculture include pH sensors, GPS sensors, temperature sensors, asset monitoring, and accelerometer sensors. In terms of their specific role as problems solving tools in agricultural production, sensors help in soil analysis, yield estimation, classification of weeds and useful crops, and pest and disease control [8]. Sensors also do have an important role in the livestock production activities of farmers. However, the types and applications of sensors are not well acquainted for farmers and researchers in developing countries. This study, therefore, tries to fill part of the knowledge gap in explaining types of sensors, their applications, and their limitations in livestock production. Real-time sensors also help in animal production and have been applied in different research activities in the past. Real-time sensors are used to monitor the individual animals' performance and conditions such as body condition, detection of disease, feed intake, feeding behavior, and welfare conditions of individual animals. As noted by [9, 10], sensors can help in mentoring the health and welfare of domestic livestock particularly dairy cattle.

2. Materials and Methods

This piece of information is prepared based on reviewing published studies on the issue of biosensors and their application in forage quality determination. In the preparation of the manuscript, 50 studies have been collected using the following keywords: bio (sensors), forages, quality (chemical composition), and bio (sensor) applications. From collected studies, 42 studies were found suitable for the review based on their relevance related to the topic. The study is organized in a manner that includes the definition of bio (sensors), common biosensors applied in pasture conditions, forage quality analysis, limitations of application, and concluding remarks.

3. Discussion

3.1. Sensors for Detection of Livestock Pathogens. In livestock production, the common pathogens can be classically assessed using plate enzyme-linked immunosorbent assay (ELISA). Though this method is important, it is usually time-consuming and requires different inputs. Recently, there are developments that enable detection of pathogens without many reagents. These technological developments are the biosensors or simply sensors (Table 1). It has been

extensively reviewed by [11] that there are recently developed technologies used in the field. Also, the reports of [12] showed that these biosensors help in achieving the results of animal health assessment and welfare in a quick manner at field conditions. A report by [13] showed that remote sensing and GIS are the most efficient techniques of prevention universal ecological hazards. These technologies could help in the diagnosis of the disease-causing organisms in a way that is easy, affordable, and quick manner.

3.2. Sensors for Grazing Land Condition Assessment. From an agricultural perspective, grasslands provide the cheapest feed source for the livestock industry; however, they contribute both directly and indirectly to climate change through the emission of greenhouse gases [14]. Global grasslands are the major and relatively cheap sources of feed for ruminant livestock and are under dynamic change. These grasslands need to be assessed to monitor their carrying capacity and healthiness for future use. Moreover, their maximum animal stocking must be maintained at a safe level so as to minimize the overexploitation of grasslands [15]. A field-level study using the global positioning system (GPS) and ground-based sensor technologies by [16] showed that it was possible to assess rangeland status of grassland and herd and concluded that data can be widely used for time series generation and overcome cloud contaminant issues. The comprehensive study by [16] showed that in matching the demand and supply of feed and livestock, optimization of forage and pasture production and better resource management is vital.

The application of real or near real-time data about the physical and/or chemical properties of the target range vegetation helps in decision-making through the application of extrapolative tools and forecasting models. In other studies [17], remote sensing systems with the capability of high spectral and spatial resolution have made it possible to derive more detailed information, so that pasture quality can be quantified accurately. In pastures, quantification of dead vegetation or nonphotosynthetic plants occupies space and competes with photosynthetic plants. These effects determine the quality of the entire pasture for grazing animals and affect the overall productivity of the grazing animals. In New Zealand, a study by [18] showed that it was possible to easily get reliable data through mapping the dead vegetation fraction accurately using AisaFENIX imaging spectroscopy.

Regarding forage species identification, a study by [19] indicated that the use of hyperspectral sensing helped them in identifying the species with a high level of accuracy. In the case of the botanical composition of a pasture, use of traditional methods can be more accurate in providing the required data; however, those methods are time-consuming and labor-intensive. Therefore, as stated by [20], it is advantageous to use modern technologies to assess rangeland botanical composition and other features of rangelands so as to cover wider areas. The application of real image analysis for the identification of forages is shown in Figure 1 [21]. Based on the findings of different researchers, it is possible to understand that in using sensor technologies, the use of

TABLE 1: Application of the sensor on grazing and behavior of livestock.

Biosensor	Application	Reference
Grazing/Feeding behavior	Pressure sensing	Braun et al. 2013; Nydegger et al. 2010; Pahl et al. 2016; Rutter et al. 1997
	Acoustic sensing	Benvenuti et al. 2016; Navo et al. 2013
	Acceleration sensors	Giovanetti et al. 2017; Herinaina et al. 2016; Mattachini et al. 2016; Oudshoorn et al. 2013.

Adapted from [43].

combined systems and methods can help more reliable information on rangeland conditions, grazing animals' distribution, and chemical composition of forages in the pasture. The study by [22] indicated that using different methods offers a realistic alternative to field-based assessment and is capable of detecting many types of rangeland degradation in addition to its cost-effectiveness.

3.3. Sensors for Forage Quality Assessment. As it is known, conventional methods are applied commonly to determine the chemical composition of forage quality. Among these are "wet" chemistry and laboratory-based NIRS (near-infrared spectroscopy) analysis methods. However, these methods are affected by the amount of the sample and sampling technique, the length of time required in every step of the analysis, and the cost and the practicality of accessing sampling sites. Recent scientific inventions are delivering optional methods such as the use of sensors in pasture quality determination. In recent years, the advancement of computers and multivariate statistical techniques has enabled the use of near-infrared spectroscopy (NIRS) in evaluating the chemical composition of many forage samples in the shortest period of time and at a less cost [23, 24]. The authors elucidate that use of both NIRS and machine learning calibration techniques could serve as an effective tool to update the monitoring efforts forages particularly in warm-season legumes by eliminating the need for classical forage analytical methods. The NIRS technology was developed and used for the determination of forage quality in the mid-1970s [25]. After its initial application, NIRS techniques have been increasingly used to quantify these forage quality parameters [26]. The NIRS analysis provides quick and low-cost results of forage composition as compared to the conventional laboratory procedure [27]. The reports of [28] showed that not only pasture biomass yield but also crude protein content can be determined using sensor technologies.

The development of sensor technologies has revealed the evolvement of lightweight multispectral cameras with remote sensors suitable for mounting on unmanned aerial vehicles (UAV) for a variety of purposes related to plant monitoring [29]. UAVs have advantages in reducing the time elapsed in the assessment of plant monitoring and increasing the precision of information. The uses of these technologies has contributed to the expansion of many areas of agriculture, including insecticide and fertilizer prospecting and spraying, seed planting, weed recognition, fertility assessment, mapping, and crop forecasting [29]. The UAV allows researchers to use high-resolution (<1 m)

spectral data collected over large areas for calculation of vegetation index that can be interpreted in units of dry matter (DM) biomass, sward height, or nutrient composition. It is possible to see the comparative evaluation of the UAV-based method of estimation of forage pastures under grazing conditions of cows (Table 2).

3.4. Sensors for Estimation of Forage Intake and Livestock Movement. It has been indicated that the use of sensors can help in monitoring grazing animal distributions in grazing lands using sensors including the global positioning system (GPS) and accelerometer [30, 31]. In the works of [32], the status and conditions of grazing behaviors of cattle elk were monitored, and the authors conclude that it was possible to observe rangeland phenomena that are important for local resource management. A report [33] showed that though grazing at the time of the high-tech world is challenging, they conclude that the technologies provide new opportunities to optimize grazing. Reports indicated that the use of digital technologies can help to follow animal and environment friendly production systems with decreased resource use call for new solutions, which could be found in digital technologies used in the entire livestock farming system.

Sensors provide an important solution for quick estimation of forage intake by larger numbers of livestock under commercial grazing conditions. In this regard, there are different technologies that are emerging and correlating sensor data aligned with specific behaviors to estimate pasture intake [34, 35]. A review made by [36] showed that it was possible to observe different levels of accuracies and based on the observation of jaw movement during chewing in grazing cattle, and the authors appreciated the use of elector mechanical sensors that have the potential to detect individual animal behavior such as bite detection and their exact location on pasture for better grazing management.

3.5. Sensors to Assess Welfare of Animal under Grazing Conditions. Assessing the welfare of grazing animals in range or pasture is usually time-consuming, but there are recent technologies that can help to accomplish animal welfare assessment in a relatively short period without investing much energy and time. Monitoring of foraging behavior is a key to ensure the fulfillment of basic health and welfare, requirements of grazing cattle and to improve the efficiency of grazing-based livestock production [37]. According to the primary industries in Australia (<https://www.foodandfarmingtechnology.com/news/livestock-monitoring/>), it was possible to monitor grazing cattle feed



FIGURE 1: Example of the image analysis on a real image. Each pixel in the image is automatically analyzed and classified as either grass (blue), clover (red), weeds (yellow), or unidentified (black overlay). (a) Example input image. (b) Automatically analyzed image [21].

TABLE 2: Comparison of the UAV-based method for estimation of estimation of herbage mass for tall fescue and dry ryegrass-based pastures rotational grazed by lactating cows.

	Biomass estimation (Kg DM/ha)				Comparison vs. UAV				
	Mean	SD	<i>N</i>	Bias	<i>t</i> -test	RMSE	RE	R^2	<i>r</i>
UAV	2017	530	52	—	—	—	—	—	—
C-Dax	1971	350	52	-46	0.37	363	18	0.53	0.73
Ruler	2073	636	52	56	0.30	386	19	0.63	0.80
Mean	2022	472	52	5	0.90	313	15	0.65	0.81

Adapted from [44].



FIGURE 2: Sensor (a) and sensor applied to grazing stock (b).

intake using sensors that match ear tags (Figure 2). Livestock grazing is a common feature of pasture-based livestock. Hence, it is vital to monitor such features in order to assess the welfare status of animals and the pasture for subsequent management. In addition, studies indicate algorithms that predict pasture intake by individual cattle based on behaviors quantified from the sensor data.

In addition to the above discussion, a review made by [38] showed that in grazing livestock, it is possible to control livestock movement using integrated sensor technology. The same source showed a schematic diagram that shows how livestock in grazing can easily be monitored under field conditions (Figure 3). Moreover, they stated that further

research is required to enhance the system of technologies at field condition for better management of animal production.

In vast areas of rangelands that take much time and energy to monitor, technologies such as accelerometers can help to monitor the status of livestock remotely [39]. The works of [40] showed that the use of different digital tools can help to graze sheep welfare, but individual conditions would vary associated with technological variations and field conditions which require further research in the field. Different reports elucidate animal behavior during grazing, as well as any movement can be easily monitored using the recently developed technologies. However, the use of these technologies may be limited for some areas or regions due to many factors as discussed.

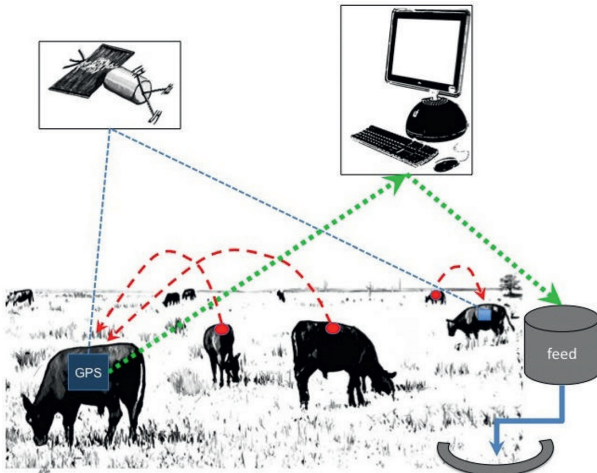


FIGURE 3: Schematic of a precision grazing system (Laca et al. 2009) [38].

4. Limitation of Application of Sensors

One of the main obstacles in using sensors in livestock production and health management is the lack of technical skills and types of equipment [41]. For example, the NIRS application, though it is relatively low cost and quick in its result, technology still needs a period of time for collecting, drying, and grinding vegetation samples. As indicated above, UAV has an important role in the estimation of yield, condition, and composition of crops or forages in a given pasture. Nevertheless, their application is limited in application for grazing [42], which might need to sort out the problems of application in future research and development efforts. The review made by [20] indicates that it was possible to apply different sensor techniques in the temperate regions that could help in farmers' decision-making. However, such technology is scanty to be applicable under most tropical conditions and can be a future focus of research and development for its application in the livestock production sector.

5. Conclusion and Future Research

In the era of digital technology, it is vital to brush existing knowledge and expand researchable issues for development purposes. Digital technologies are sensors in agriculture, particularly in livestock productions which are currently used in developed countries. Though not yet fully understood and applied in developing countries, the knowledge of the application of sensors would help the future of livestock production in these parts of the world. Hence, this mini-review was prepared based on earlier reports on the issues. Sensor technologies are easier and more convenient to collect information about livestock production, health, and welfare under grazing conditions. Moreover, using recent technologies, it is possible to monitor livestock grazing and forage quality conditions in pasture lands. These technologies if applied properly can help in saving time and cost mainly when large samples are required to be analyzed.

However, the current knowledge in this regard is limited in the field; hence, awareness creation, future research, and development efforts are required in the area, particularly in developing countries.

Data Availability

No data were used to support this study.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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