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Precision livestock production: tools and concepts

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ABSTRACT - Precision livestock production (PLP) is the augmentation of precision agriculture (PA) concepts to include all components of agroecosystems, particularly animals and plant-animal interactions. Soil, plants and soil-plant interactions are the subjects of PA or site-specific farming, where the main principle is to exploit natural spatial heterogeneity to increase efficiency and reduce environmental impacts. For the most part, PA has been studied and developed for intensive cropping systems with little attention devoted to pastoral and agropastoral systems. PLP focuses on the animal component and exploits heterogeneity in space and among individual animals towards more efficient and environmentally friendly production. Within PLP, precision grazing consists of the integration of information and communication technologies with knowledge about animal behavior and physiology to improve production of meat, milk and wool in grazing conditions. Two main goals are to minimize overgrazing of sensitive areas and to maximize the quality of the product through enhanced traceability. An integrated precision grazing system is outlined with its components: sensors of animal position, behavior and physiological status, real-time transmission of information to a decision support system, and feed-back through a series of actuators. Control of animal movement and diets is based on knowledge about species specific responses to various stimuli within the paradigms of flavor aversions and operant conditioning. Recent advances in the technologies and instrumentation available are reviewed briefly and linked to current livestock identification systems. The precision grazing vision is presented in full and the areas that need further research and development are discussed.

Key Words: animal position, animal behavior, plant-animal interaction, precision grazing

Precisão de produção de gado: ferramentas e conceitos

RESUMO - A precisão de produção de gado (PPG) se constitui em ampliação do conceito de agricultura de precisão (AP) e que inclui todos os componentes de ecossistemas agrícolas, especialmente as interações animais e planta-animal. O solo, plantas e as interações solo-planta são temas da AP ou de locais específicos em cada fazenda, onde o principal objetivo é explorar a natural heterogeneidade espacial para aumentar a eficiência e reduzir impactos no meio ambiente. Para a maioria das situações a AP tem sido avaliada e desenvolvida em sistemas intensivos de cultivos de grãos e pouca atenção voltada para sistemas de pastejo e sistemas de integração lavoura e pecuária. A PPG tem como foco o componente animal e explora a heterogeneidade no espaço e entre animais individuais visando sistemas de produção apropriados ambientalmente e maior eficiência. No PPG o pastejo de precisão consiste da integração de tecnologias de informação e de comunicação com conhecimentos sobre o comportamento animal e sua fisiologia e isto visa o aumento da produção de carne, da produção de leite e da produção de lã, realizada em situações de pastejo. As duas metas mais importantes são minimizar em áreas suscetíveis o pastejo excessivo e maximizar a qualidade do produto animal mediante o aumento da traceabilidade. Um sistema de pastejo de precisão integrado é descrito por seus componentes: sensores de posição animal, o status fisiológico e comportamental, o tempo real de transmissão da informação para um sistema que suporta a tomada de decisões e a resposta mediante várias informações para um instrumento. O controle dos movimentos dos animais e da escolha da dieta é baseado em conhecimentos de respostas específicas de espécies a vários estímulos do meio ambiente dentro do paradigma de aversão ao sabor e condicionamento operante. Avanços recentes disponíveis em tecnologia e instrumentos são revisados brevemente e associados aos atuais sistemas de identificação de rebanhos. O conceito do pastejo de precisão é apresentado de modo ampliado e áreas que necessitam de futuras pesquisas e desenvolvimento são discutidas.

Palavras-chave: comportamento animal, interação planta animal, pastejo de precisão, posição animal

Introduction

The world faces unprecedented environmental challenges where livestock production is in center stage. A controversial report by the United Nations (Steinfeld et al., 2006) indicated that livestock grazing occupies 26% of the ice-free terrestrial surface, and that grazing has led to degradation of 20% of pastures and rangelands (73% of

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rangelands in dry areas). Regardless of whether livestock impacts are less bad or worse than other sectors, the fact is that livestock production creates immense benefits for humans, but it also has negative consequences on the land. Thus, we have to improve livestock systems to minimize environmental impacts while maintaining high productivity, quality and energy efficiency.

As markets and economies become global, new opportunities and challenges arise. Red meat producers from many countries can now compete in high-end markets where success depends critically on being able to deliver a safe healthy product. This is particularly important for producers from Argentina, Southern Brazil, and Uruguay, where crucial markets depend on control of foot-and-mouth disease, low risk of bovine spongiform encephalopathy, and certification of origin of organic and grass-fed beef (Boland et al., 2007).

In this context, I propose to extend the concepts of precision agriculture to livestock production at all levels. Precision livestock production refers to the exploitation of multiple levels of heterogeneity and nonlinear responses in the production processes to increase profitability and reduce environmental impacts. The approach seeks to make use of large quantities of specific information about individual animals and locations to optimize performance. In this paper, I focus on a system for precision grazing management as part of the precision livestock production complex. This work integrates knowledge about animal behavior, grazing management, global positioning and communications technology to simultaneously address the environmental and marketing challenges and opportunities posed by grazing management. The goal is to create a cost-effective system that provides detailed product traceability and allows flexible grazing management to minimize environmental impacts while improving economic efficiency.

Integrated system

The proposed system is designed to provide three basic and independent functions: animal position and behavior, remote herding and feeding, and health

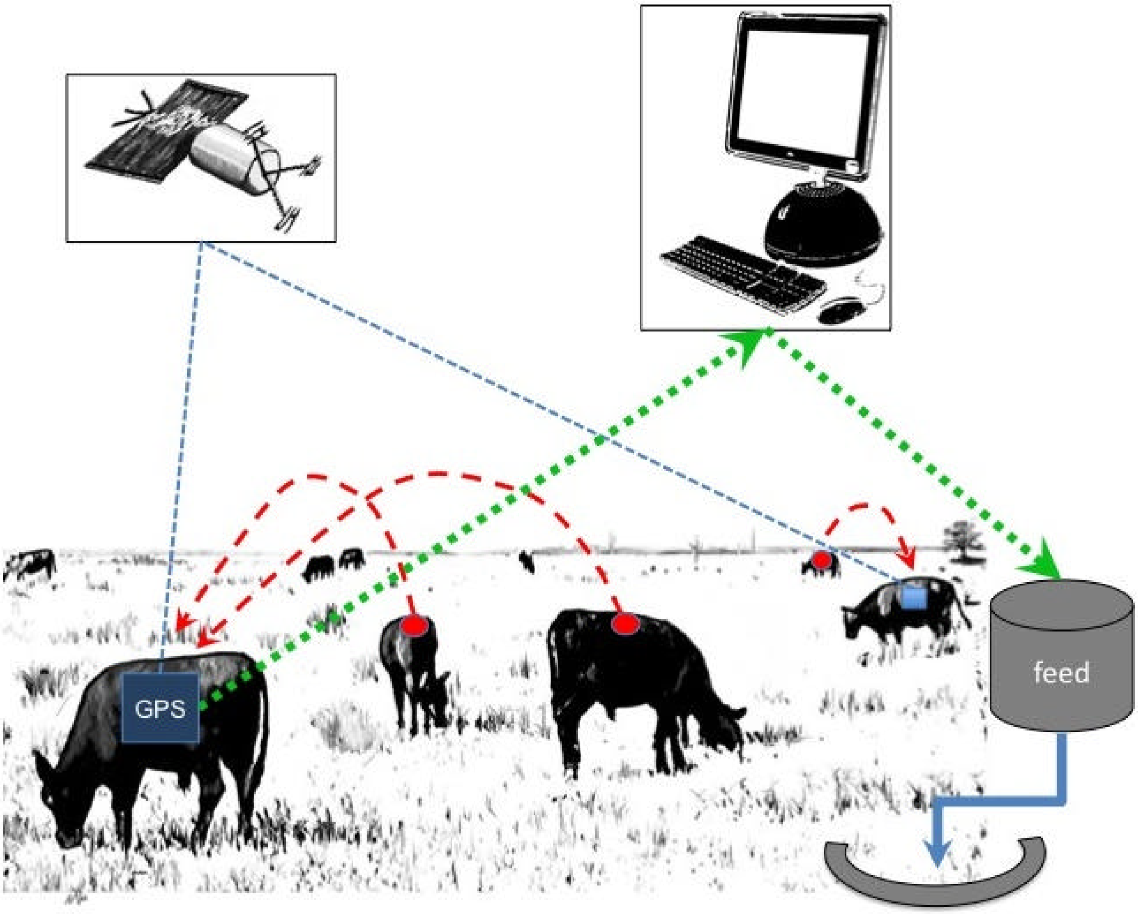

Figure 1 - Schematic of a precision grazing system. Master collars with GPS and behavior or physiology sensors on certain individuals (box) receive information from nearby animals fitted with short-distance "slave" transmitters (circles). Master collars send all information in real time to computational and decision-support centers (large dotted arrow), which in turn send control signals to operate a series of feeders, gates, and audiovisual stimuli to direct animal movement.

management and precision traceability (Figure 1). The first and third functions involve mostly recording and transmission of data from the animal to the manager, and processing data into management information. The second function incorporates the ability to remotely effect management actions. The third function provides information for the purpose of animal identification, certification of origin and health management. This last function is similar to the first one, but separate in design to allow use of the other two functions independently when certification and regulatory data is not desired or appropriate.

At present, the system is at the design and prototype stage. We are looking at the best technologies to achieve a good balance of autonomy, data intensity, precision, and cost. Because of the differences in the communication infrastructure and markets among countries, it is likely that different configurations will work best under different conditions.

Behavioral basis

General principles of animal behavior and specific characteristics of the behavior of ruminant livestock provide a basis to develop a system to manage livestock's dietary and spatial behavior. The study of flavor aversions and their use for dietary training has been intense and prolific in the last twenty years (Distel & Provenza, 1991, du Toit et al., 1991, Provenza, 1995, 1996a, Thorhallsdottir et al., 1990, Villalba & Provenza, 2009). Conversely, the study of instrumental learning or operant conditioning of livestock has been very limited, presumably because it was perceived as having little applicability. In this section, I consider both as components of the behavioral basis for controlling animal movement and diets with the precision grazing system.

Flavor aversions and preferences

Contrary to what was assumed originally, ruminant livestock have a gut-brain system with the ability to form clear and long-lasting flavor aversions, much like the system in monogastric animals (Dutoit et al., 1991). Provenza (1996b) states that an aversion is "the decrease in preference for food just eaten as a result of sensory input (a food's taste, odor, texture, i.e., its flavor) and postingestive effects (effects of nutrients and toxins on chemo-, osmo-, and mechano-receptors) unique to each food." The mechanism for flavor aversion involves neural connections through the vagus nerve between the gut and the emetic center of the brain that work completely independently of the animal's consciousness or cognitive ability (Provenza et al., 1994). Flavors of novel foods are associated with the postingestive consequences after a certain delay such that later exposure to the same flavor stimulates the emetic system and results in the avoidance of foods that caused the gastrointestinal (GI) discomfort. The flavor aversion mechanism likely evolved as a consequence of the interaction of animals with harmful plants, and it has adaptive value. Yet the mechanism is fallible, particularly if the natural correlations between flavor and GI consequences are manipulated to promote human objectives other than the optimization of animal nutrition, such as protection of crops and trees. By allowing animals to sample the crops as novel foods and dosing them with a substance that produces GI discomfort, a flavor aversion to the crop is created, although the crop is completely safe.

Flavor preference is a functionally related process by which animals learn to prefer flavors that are associated with positive postingestive and nutritional consequences (Myers, 2007). Flavor preference has been documented in ruminants, and the types of responses to training can be rich (Villalba & Provenza, 1996, 1997a, b, 1999, 2000a, Villalba et al., 1999). For example, Ralphs et al., (1995) found that sheep could be trained to prefer foods with a certain flavor by associating the flavor with an intra-ruminal dose of glucose. Remarkably, they also found that high dose of propionate generated an aversion, which indicates that nutrients can act as positive or negative stimuli depending on concentration.

Flavor aversion and preference learning have multiple characteristics that can be exploited to manipulate diets. Neophobia, extinction, sampling, generalization, and complementarities are some of the most relevant. Neophobia is the reduced intake of novel foods. It can be enhanced by creating multiple aversions to novel flavors (Dutoit et al., 1991) or reduced by addition of familiar flavors to news foods (Launchbaugh et al., 1997), because animals generalize mostly on the basis of flavor and not form of plants (Ginane & Dumont, 2006), although correlations between form and flavor could be developed via classical conditioning. Neophobia is more intense when novel foods are in unfamiliar environments (Burritt & Provenza, 1997). Extinction is the process by which aversions are attenuated over time. Animals always sample foods, even when the have an aversion to the flavor. If the sampling does not result in negative consequences, the intake of the food increases progressively. Persistence of aversions can be enhanced by providing alternative forages, particularly when the alternatives are complementary to the basal diet (Kimball et al., 2002). Finally, ruminants have a greater susceptibility to form long-term preferences and aversions when they are young (Launchbaugh et al., 2001), and they are able to regulate intake of chemicals that ameliorate the deleterious effects of plant toxins (Provenza et al., 2007, Villalba et al., 2006).

Thus, animals can be "trained" to avoid perfectly safe foods and to increase their preference of plants that are not naturally preferred (Villalba & Provenza, 2000b). Dietary training will be the basis for controlling behavior at the finest level of resolution, such as to modify the grazing pressure on certain species when they are interspersed with others.

Operant conditioning

Operant conditioning or instrumental learning is the recurrence of behavior that is effective when animals are exposed to the same situations repeatedly, and it involves the elimination of those behaviors that are ineffective (Staddon & Ettinger, 1989). Thus, when dogs perform "tricks" upon being prompted by their master, they show the results of the operant conditioning mode of learning. The situation is set by the master's command, and the dog responds with a behavior that is effective to obtain a reward, typically of food. Operant conditioning is commonly used to train animals to do tasks or "work" to obtain rewards. In actuality the rewards can simply be opportunities to perform more desirable behaviors according to Premack's principle (Staddon & Ettinger, 1989). Common knowledge shows that domestic animals can learn to perform extremely complex behaviors through operant conditioning, and that they can develop high levels and intensity of responses.

Cattle and sheep have been trained to perform complex spatial and foraging tasks using both positive and negative reinforcement. Edwards et al., (1996) and Laca and Ortega (1995) showed that sheep and cattle readily associate visual cues (clover sods and colored flags, respectively) with food rewards. Cattle (Laca, 1998) and sheep (Hewitson et al., 2005) exhibited the ability to respond with different foraging strategies depending on the spatio-temporal nature of the food rewards. When food was predictable in space and time, animals implemented localized searches based on spatial memory, but when food was unpredictably located, animals searched in a systematic manner. The resolution of conflicts between spatial memory and visual cues appears to have a pattern. When sheep had learned the locations of the food by experience, they first searched in locations where food was in previous experimental sessions, and then, they used the visual cues (Edwards et al., 1996). Langbein et al., (2006) proved that goats can learn operant discrimination tasks under self-regulated access to an automated device. Goats became better at learning new symbols as they were exposed to new tasks, showing that they developed "learning sets" or learned to learn. Learning was best when animals were in stable groups and social environments (Baymann et al., 2007).

The relationship between the characteristics of rewards, including the traditionally called "schedules of reinforcement," (Skinner, 1958) is particularly important for precision grazing. Behavioral experiments with other animals (mostly rats and pigeons) show that the rate and intensity of behavioral responses can be modified dramatically by the schedule of rewards. Fixed interval schedules, where the reward becomes available after a fixed interval, elicit a burst of responses starting a few seconds before the interval is up and ending abruptly after the reward is obtained. Conversely, variable interval schedules where each interval is randomly set from a given distribution, promote a constant rate of responses because there is always a probability that reward will follow the behavioral response. A fixed ratio FRx schedule provides a reward for every x responses, whereas in a variable ratio schedule the number of responses required for a reward varies around a certain mean. It has been shown for a variety of mammals and birds that responses follow the patterns shown in Figure 2, and that animas take longer to learn interval than ratio schedules (Staddon & Ettinger, 1989).

The relationship between response rate and schedules of reinforcement, and the characteristics of operant conditioning are crucial for the development of effective methods to move and contain livestock in large pastures. Although these relationships have been studied in many species, there is little information about ruminant livestock. Species-specific information is necessary for development of training programs because innate predispositions are likely to differ depending on the environments where behaviors evolved. For example, Langbein et al., (2007a) determined that goats have a preference for certain symbols, and that learning can be enhanced or slowed depending on which symbols are associated with the reward. Moreover, the ability to learn tasks that depend on discrimination of stimuli depends on perceptual ability, which is typically different among species. Therefore, there is a need for fundamental research about the characteristics of perception and learning of ruminant livestock in order to be able to design optimal training methods.

Operant conditioning has a characteristic that facilitates training of many domestic animals: stimuli can be "chained" such that a secondary reinforcement signal (e.g., a clicking sound) helps to bridge the time gap between the response (lever pressing) and the primary reinforcer (food). "Clicker

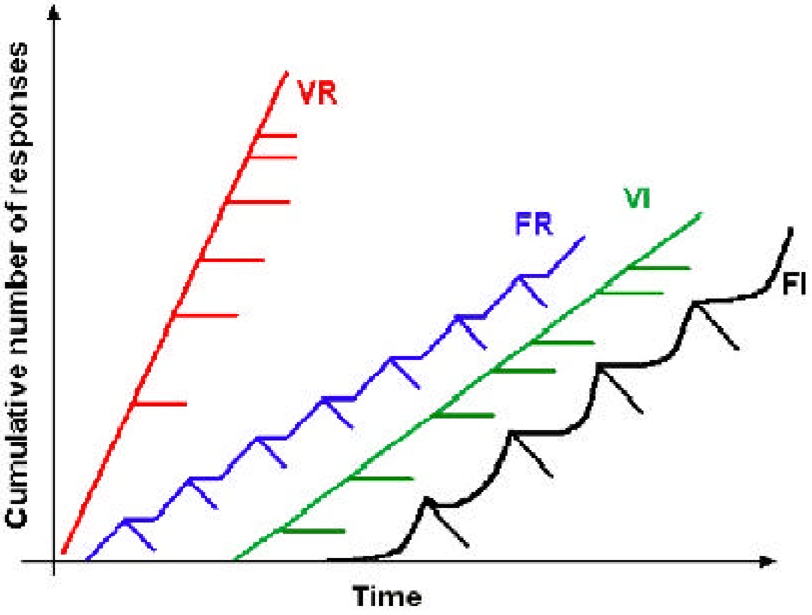

Figure 2 - Typical patterns of response to various schedules of reinforcement. Schedules of reinforcement can be combined to elicit complex patterns of response. VR: variable ratio, FR: fixed ratio, VI: variable interval, FI: fixed interval. The tic marks indicate the time when a reward (pellet of food) was released.

training" is used routinely for dogs and other mammals, but it has not been sufficiently tested in farm animals. Results with horses appear to have been inconsistent. McCall and Burgin (2002) found that horses trained with primary and secondary (clicker sound) reinforcement performed better than controls when exposed only to the secondary stimulus. However, the learned behavior was extinguished quickly in the absence of the primary reinforcer. Conversely, Williams et al., (2004) did not find an effect of secondary reinforcement. Dwarf goats trained with a secondary reinforcer (sound) presented together with the primary one (water) proved to remember and learn more quickly and efficiently than goats without the secondary reinforcement (Langbein et al., 2007b). In this case, the secondary reinforcement included different sounds for correct and incorrect responses, and the appropriate sounds were presented simultaneously with the reward or immediately following the incorrect response.

Visual stimuli seem to be more readily associated with food rewards than acoustic ones in cattle. Uetake and Kudo (1994) trained cattle to perform a task when presented with a light and sound simultaneously. Then, cattle were tested under three treatments: both signals simultaneously as during the training, only sound, and only light. The total number of correct responses was similar in the light + sound and light treatments, but when exposed only to sound animals performed much worse, which was interpreted as a visual dominance, at least in relation to food rewards. Further, the authors determined that there is color dominance from green to white to red. This is likely related to the fact that green plants are usually more nutritious than those that reflect more light in other bands of the spectrum. The poor response of cattle to sound signals was corroborated by Wredle et al., (2006) when attempting to train dairy cows to approach the milking parlor in response to a sound. I suspect that sound signals have a low probability of being associated with food rewards in herbivores, and that they are particularly ineffective when the desired responses are directional in nature and the sounds originate from devices mounted on the animals, as typically implemented in "virtual fencing" applications (Anderson, 2007; Bishop-Hurley et al., 2007).

Instrumentation

A control system consists at least of sensors that measure variables related to the system's state and actuators that provide input of mass, momentum or information to the system towards directional modification of the state. A precision grazing system must have defined variables that need to be measured, and specific actions or inputs to create a repertoire of management actions. Animal state is estimated by the history -up to a recent time- of position, activity, temperature, live weight and other physiological variables of all individuals in the herd. The state of the rest of the ecosystem, particularly of the plant community can be characterized by the amount and composition of herbage over space, say for each 10 x 10 m or 30 x 30 m area of the landscape available. Other attributes such as position of shade, natural watering points, and topography can be considered constant or part of the system "structure" instead of its changing state. In this paper I focus on the animal component, although the plant component can be equally important and variable, and it is also the subject of sensors and inputs as in precision agriculture.

Identification

Development and commercialization of animal identification systems is very advanced. A variety of systems are available, some of which work reasonably well and have been adopted at the country level. Canada adopted a mandatory national cattle and bison identification system in 2001, followed by the sheep system in 2004 (Canadian Food Inspection Agency, 2008; Stanford et al., 2001). All animals must be identified and tagged before leaving their place of origin or upon entering the country. Chile implemented a registry and traceability system for bovines whereby all ranches and animals must be registered (Felmer et al., 2006). Like the system adopted in Uruguay, the Chilean system mandates that all animal movements be recorded in the national system. These systems greatly facilitate the traceability and certification of products, particularly of beef, and therefore are crucial tools to minimize the losses and market disruptions caused by "mad-cow" disease and foot-and-mouth disease. The types of devices used for identification are reviewed by Felmer et al. (2006). These devices are "passive" in the sense that they do not record or relay any information unless they are queried by another device that also provides the necessary energy for the transmission.

The kind of devices necessary for precision control of grazing would serve as "roving" querying stations that could also report and register animal movements in real time. The resulting integrated system would be vastly superior to the current systems at least in two areas: real-time information relay and high spatial resolution of records. Higher spatial and temporal resolution of information will significantly enhance the ability to detect and stop disease outbreaks. One can only begin to imagine all the uses that producers and consumers will find for such information, but it is safe to predict that it will facilitate billing of grazing fees, tracking and accounting of animal ownership, recovery of lost animals, thoroughness of health treatments, and herd management in general.

GPS

The use of GPS "collars" for livestock and wildlife has become widespread in the last ten years. This opened the possibility of recording detailed position information for long periods of time, thus allowing a more complete understanding of the habits and causes of spatial distribution of ruminants. Clark et al. (2006) developed a low-cost system that incorporates the ability to upload programs to and receive data from the roving units using radio technology without the need for permanent frequency allocations. Other commercial units are available, but they are more expensive and have lesser capabilities.

Current GPS technology can determine position of individual animals with a precision of 10 m or better. The position information can be stored on small flash cards together with large amounts of behavior and physiological data and it can be transmitted to a management center in real time or in periodical sessions. Given the history of prices in electronic technology, it is very likely that with the proper investment in research and development we can have cost-effective herd information systems with which we will be able to see where and how all of our animals are and what they are doing at any time.

Animal behavior sensors

Commercial GPS collars usually include three sensors: temperature, fore-aft movement, and left-right movement. The data recorded by these sensors is somewhat ambiguous, but models can be developed to infer activity. Buerkert & Schlecht (2009) found significant differences in accuracy and precision among different units, particularly in rugged terrain. Ungar et al. (2005) found that most grazing activity could be identified with models developed, but frequently other activities were classified as grazing. Overall misclassification rates were 12-14% for all activities. Because GPS precision is worse than 5 m (Agouridis et al., 2004), recorded coordinates vary even when animals are stationary. On the other hand, long distances between successive records indicate directional movement not related to grazing. Although Ungar et al. (2005) concluded that distance alone is a poor predictor of cattle activity, Putfarken et al. (2008) classified activities as grazing if distances between fixes at 5-minute intervals were between 6 and 100 m, and obtained 94.3 and 89.4 correct classification rates for cattle and sheep.

Various types of sensors are necessary for a detailed record of behavior. Mercury switches have been useful to document not only head movements but also walking and lying behavior. The system used by Champion et al. (1997)

recorded steps and lying/standing in sheep and cattle with more than 90% concordance between recorded and directly observed behavior. Perhaps the most developed system to measure grazing behavior is the IGER Behaviour Recorder (Rutter et al., 1997), which records jaw movements with concordance greater than 90%. However, this system ignores the fact that ruminants combine biting and chewing during grazing (Ginnett & Demment, 1997; Laca et al., 1994; Laca & WallisDeVries, 2000), and it has to be improved accordingly.

Acoustic monitoring of grazing (Laca & WallisDeVries, 2000) provides rich information that can be used not only to classify behaviors but also to estimate intake rate and even potentially diet composition in simple pastures (Galli et al., 2006). Ungar & Rutter (2006) determined that the acoustic method is significantly better than the IGER Behaviour Recorder for classification of jaw movements, and indicated that automated decoding systems needed to be developed for the acoustic method to be of practical use. Such decoding system has been created and exhibits acceptable accuracy but needs further development (Milone et al., 2009).

There is a rich history of sensor development to detect and record kind and rate of herbivore behavior. Sensors have been tested for measuring head angle (Schwager et al., 2007), head acceleration, leg acceleration, steps (pedometers), swallowing, jaw movements, biting and chewing sounds, weight, heart rate (Brosh et al., 2006), core temperature (Eigenberg et al., 2008), etc. These sensors were reviewed by Frost et al. (1997).

Monitoring of live weigh and health

Sensors and techniques for weight and heath monitoring are well developed for dairy production under confined conditions. Behavior and changes in behavior can be used to detect health problems before disease affects animal productivity. Gonzalez et al. (2008) were able to detect 80% of health problems related to ketosis, locomotion and lameness at least one day sooner than the farm staff by analysis of short-term feeding. Ketosis and acute lameness were manifested by downward spikes in intake, whereas chronic lameness was detectable by a downward trend in intake over several days.

Firk et al. (2002) had success in using a pedometer and advanced time series analysis to detect oestrus in dairy cows, but the system yielded an excessive number of false positives. Core temperature of dairy cows can be estimated with a permanent intra-reticular bolus that is commercially available, however, temperatures need to be adjusted to be comparable to rectal temperature (Bewley et al., 2008).

Reliable remote methods for weighing cattle have been developed and tested. Most of these devices allow passive entrance of animals into a chute with a weighing platform and ID tag reader. Animals enter the chute to access water or feed. Remote weighing is less disruptive to animals and works effectively (Charmley et al., 2006).

Virtual fences

Being able to control the spatial behavior of livestock without having to build expensive and inflexible fences is the next frontier of grazing management, particularly in more developed countries where herding is too expensive or simply impractical. Cattle respond to tactile, visual an aural stimuli, and can be trained to respond in specific manners. Researchers have attempted to create devices that can train livestock to stay away from certain areas or to move in a desired direction by providing signals followed by punishment when the incorrect response is exhibited. In general, these "virtual fences" have not has as much success as desired, but were effective in modifying animal movement (Bishop-Hurley et al., 2007). A complete review of the concept of virtual fences and its current state is given by Anderson (2007).

I believe that the concept of virtual fences can be expanded to achieve better results. Instead of thinking of devices to keep animals from entering certain areas and instead of using exclusively negative reinforces such as electrical shocks, we should design general systems to control or guide animal movement using positive reinforcement and carefully designed sets of stimuli and reward schedules. The animal control system should be flexible and geared toward using animals both as product and as agents for landscape management (Butler et al., 2006).

Potential deficiencies of the typical virtual fence paradigm are the types of stimuli used and their lack of a directional component. When exiting the "fenced" area, animals are warned with a sound that originates on the collar or ear tag attached to them, and then they are punished by a non-directional shock that also originates on the same device. This taxes animals to create a new cognitive map based on linking local stimuli with whatever spatial stimuli they can see in the landscape.

I propose that we investigate the control of movement by using directional stimuli that originate form specific locations in the landscape, and that correct behaviors be rewarded with the aid of chaining of stimuli to accelerate the shaping of responses. Learning about stimuli that come from the environment is natural to animals and has been subject to evolution and learning. This is common knowledge among people who handle and manage livestock. Cattle learn quickly to go to the feeding location at the usual feeding time. Animals learn to approach the feeding call and the sound of the feed and feed bags as they are opened. They can learn complex spatial tasks using both spatial memory (using landscape elements for orientation) and rapidly acquired visual stimuli such as colored flags (Laca & Ortega, 1995).

Training and control

The actuator side of a precision livestock production will certainly incorporate control of plants, control of animals and control of the plant-animal interactions. Control actions concerned exclusively with the plant-soil complex fall within the realm of traditional precision agriculture with the caveat that in rangeland systems there are significant impediments to the use of traditional machinery and methods. Control that concerns exclusively the animal component is fairly well developed for confined systems such as in dairy production (Schellberg et al., 2008) where behavior, health, weight, production and feed intake are routinely monitored for uniquely identified individual animals (Gonzalez et al., 2008; Halachmi et al., 1998; Mottram, 1997; Pastell et al., 2008a; Pastell et al., 2008b; Peiper et al., 1993) and animals are fed and managed intensively. The novel areas that require the most development are in the realm of controlling animals and plant-animal interactions in complex grasslands and rangeland systems.

Our design incorporates programmable and remotely controlled reward and stimuli stations based on commercially available feeders (e.g., www.ontimefeeders.com) with additional hardware to display visual signals and emit sounds. A network of stations located in strategic landscape positions is used to both train and later control animal movements by rewarding the desired behaviors with a highly palatable feed that is distributed according to any schedule of reinforcement desired.

Conclusions

Livestock production is in a period of rapid adjustment and development, both regionally and globally. There are intense pressures and concurrent opportunities associated with the need to produce safe and environmentally friendly livestock products. This created the need and opportunity to use animal identification and traceability systems at the national level in many countries.

Simultaneously, advances in electronic communications and GPS technologies fueled by consumers of information drove major declines in the prices and improvements in performance, opening a window of opportunity to create cost-effective systems for large scale precision livestock production. We are in the middle of the period when the fate and reach of this new kind of livestock production will be defined, and there are some clear aspects that need to be resolved.

Precision livestock production in grasslands and rangelands will include two related systems: information gathering and management inputs. Multiple sensors exist to gather information about animal behavior, GPS devices prices are becoming affordable for use at the herd level, and virtual fencing applications are being developed. Further development is necessary to improve the system for application management inputs to modify production and animal behavior. In specific, more research is needed to generate better sets of stimuli and training devices for livestock, including remotely controlled feeders. Finally, components have to be fully integrated into complete systems that can be commercialized, much in the way precision agriculture proceeded.

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