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RESEARCH ARTICLE

Monitoring Cattle Grazing Behavior and Intrusion Using Global Positioning System and Virtual Fencing

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ABSTRACT

The inadaptability of the frightening devices to the behavioral-change exhibited by grazing animals has been a great challenge in developing animal detection and recognition system that can prevent animal intrusion to a prohibited area. Animal distribution is something that is challenging and that does not have an immediate answer to. In fact, literature shows that just in the last few years, more than 68 different strategies have been used trying to affect animal distribution. These include putting a fence in, developing drinking water in a new location, putting supplemental feed at different locations, changing the times feed is put out, putting in artificial shade so that animals would move to that location, using identification means such as ear tags, radio frequency identification, tattooing, marking, branding, and biometrics. There are a host of frightening strategies that have been used to scare animals from intruding prohibited area; these include installing frightening devices such as explosive materials, acoustics and bioacoustics gadgets, and so on. Moreover, they all work under certain conditions; some of them work even better when they are used synergistically. Sooner or later, these animals become accustomed to most of the frightening techniques put in place to prevent them from going beyond their boundaries or intruding the prohibited area. Virtual fencing (VF) and global positioning system (GPS) are the recent technology developed to handle the challenges that come with animal grazing behavior. Recent advances in GPS and VF technology have allowed the development of free-range and lightweight GPS collar tools suitable for monitoring animal behavioral changes.

Key words: Biometrics, cattle collar, global positioning system technology, grazing animal, radio frequency identification, tracking, virtual fencing

INTRODUCTION

Animal husbandry is often referred to as a resource.[1] Humans from history have benefited economically and scientifically from animal husbandry at various levels. However, if not controlled, negative values of animal include damage to the activities in agricultural fields and grazing related human injuries, collisions, and even death. Farmers-herdsmen conflicts are defined by the negative interaction between farmers and herdsmen due to intrusion of cattle into agricultural fields, which result in a negative impact on people and their resources. These conflicts occur when cattle infringe on the activities in agricultural fields thereby leading to destruction and even death. Conflicts between farmers and herdsmen are increasing,[2] and in many parts of the world damage caused by cattle creates significant economic challenges to human communities. Hence, the goal of every farmer is to reduce these negative values so as to achieve the objectives of farming.[1] Farmers-herdsmen conflicts are not an isolated phenomenon, and there are many scenarios where cattle can cause serious problems for human activities. Both the nature of the conflict and the complexity of intrusion can be very different in these scenarios, for example, the problems can be isolated to smaller areas in industry and residence, whereas in farming, the problems cover much larger region.

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Effective management and control of activities in agricultural fields are vital to reduce the negative impact of farmers-herdsmen conflicts. A wide range of devices and methods are used in the management and control; however, their effectiveness is often highly varied due to habituation or limited impact.[3,4] Habituation is the gradual adaptation to controlling and frightening stimuli, and it is a major limitation to current controlling and frightening devices. The use of frightening devices is a popular approach to management and control of activities in agricultural fields. However, both deadly and non-deadly methods have been used in the management and control of activities in agricultural fields. The use of deadly control is often controversial as a method for the management and control of activities in agricultural fields. The public accepts the use of deadly method when there are no alternatives. However, they also believe that continued research toward non-deadly method is needed. This motivates research toward more efficient, ethical, and non-deadly methods for the management and control of activities in agricultural fields. Virtual fencing (VF) – a relatively straightforward technological innovation and global positioning system (GPS)-equipped free-range cattle that can be nudged back within virtual bounds by stimulus-delivery devices – could profoundly reshape our relationships with domesticated animals, the landscape, and each other. GPS technology can provide researchers with efficient and accurate information on grazing behavior. Previous research efforts focused on tracking animals using data gathered by observation. Recent advances in GPS technology have allowed the development of lightweight collar tools suitable for monitoring animal grazing patterns and behavioral changes. Precision animal location recording allows researchers to evaluate pasture utilization, animal performance, behavior, and boundaries violation. Researchers may assess the merits of pasture or paddock shapes and sizes, fence designs, grazing systems, forage composition and availability, location of shade, water, and supplements, and other variables that affect cattle operations.

Smart livestock collars allow animals tracking through GPS and set virtual boundaries with an easy-to-use smartphone application. A cloud-based management system gives herdsmen a complete view of their herds in real time. Advanced technology monitors the well-being of animals by collecting and analyzing behavioral data and sending alerts when anomalies occur. Information is tracked and aggregated over time, helping herdsmen make informed, long-term decisions about the well-being of both their herds and the agricultural fields around the grazing land. The innovative GPS and VF solution help herdsmen to minimize operating costs, reduce animal losses, destruction of farm land, and increase the safety of both animals and agricultural crops.

In this paper, we set the following as the objectives: (1) To review previous monitoring technology; (2) to explain VF and GPS as animal tracking and monitoring technology; and (3) to describe VF and GPS tracking collar application for cattle; this technology could profoundly reshape our relationships with domesticated animals, the landscape, and each other. The rest of the paper is organized as follows. In Section 2, we review some works that are related to the title, in Section 3, we present the materials and methods used in achieving the paper objectives, the results are presented and discussed in Section 4, and Section 5 concludes the paper.

RELATED WORKS

In Kumar *et al*.,[5] facts are on ground that the previous traditional cattle identification and monitoring methods such as ear notching/tagging, tattooing, branding, marking, or even some electrical identification methods such as radio frequency identification (RFID) are not able to provide enough reliability to cattle identification and monitoring due to theft, fraudulent, duplication, and low frequency.[6] The ear-tattoo-based marking techniques are highly applicable for tracking and identification of several cattle breed associations such as Brown Swiss, Red Poll, and Milking Shorthorn breed associations.[7,8] The distinct artificial marking techniques, such as embedding of microchips, ear-tattooing, and hot-iron techniques are required for identifying individual cattle, but these techniques give the defects on the cattle.[8,9] On the other hand, the collar-id and ear-tagging based identification techniques are examples of semi-permanent animal identification approaches for the identification of individual animals.[10,11]

The ear-tagging based verification and identification techniques are not competent to identify and monitor individual cattle.[8,12] The monitoring and tracking of individual cattle based on embedded unique tag numbers can be easily lost.

The ear-tagging based techniques suffer from the major problems for verification and identification of animals. A very few investigations have been done to date on animal sounds which is a part of environmental sounds.[13] These environmental sounds are varieties of creature's sounds including human sound. Many animals produce sounds either for communication or as a by-product of their living activities such as eating, moving, or flying.[14] Researchers for a long time have been facing difficulty of acquiring high quality acoustic data such as alarms and distress calls in adverse environments, and inadequate knowledge about how animals produce and perceive sound. This is also a challenge to behavioral recognition and frightening devices. By having the recognition system, the security of some areas can be improved.[15,16]

However, to get the security of these areas improved, the behavioral changes of the target species should be adapted to by the detection and recognition system. In a frightening scenario, the intended result is flight, based on fear. Therefore, an adaptive system needs to be able to monitor change in behavior, based on the ability to recognize behavior, and react accordingly. Methods used within animal behavior research include attached tracking devices like GPS[17] or other wireless transmitters in a wireless sensor network,[18] or accelerometers, measuring the movement of specific parts of the animal body.[19] Acoustic information has also been used in chewing behavior recognition of cows;[20] however, these methods also rely on attaching a device on the animals. These methods are not suitable when the purpose of the animal behavior recognition is to utilize the results in a free-range system as it is not possible to attach these devices on the animals. Therefore, non-invasive sensors, like cameras, are a necessity in this context. In Steen,[21] wildlife damage management involves the timely use of a variety of cost-efficient control methods to reduce wildlife damages to tolerable levels. Frightening devices are important tools used in wildlife damage management to reduce the impacts of animals,[11] and the goal of using frightening devices is to prevent or reduce the damage of animals and damage caused by animals by reducing their desire to enter or stay in an area.[22,23] Furthermore, the timing of activation of frightening devices is often a critical factor, and random or animal-activated devices may reduce habituation.[22,23] Here radar, or motion sensors can be utilized,[24] however, these methods are not very cost-efficient and non-specific. A type of acoustic stimuli that are promising for future frightening devices is bioacoustics.[25] Bioacoustics is animal communication signal, and this communication includes alarm or distress calls. Alarm calls are vocalizations used to warn other animals of danger. It is concluded that the use of distress calls proved to be very effective, whereas the carcasses had no effect.

Evaluation of a deer-activated bioacoustics frightening device for reducing deer damage in cornfields is presented in Gilsdorf *et al*.[26] This paper was motivated by the need to reduce the damage caused by deer in cornfields. This was aimed at evaluating ungulate-activated bio-acoustics frightening devices using frightening devices. The system was based on alarm, alert, and distress calls which were played back from multiple speakers. The calls were altered in sequence of play, frequency, duration, and interval, thus providing variability in the frightening stimuli. The device was not effective in reducing damage: Track-count indices (F1, 4=0.02, $P = 0.892$), corn yield (F1, 9=1.27, $P = 0.289$), and estimated damage levels (F1, 10=0.87, $P = 0.374$) did not differ between experimental and control fields. The size (F2, 26=1.00, $P = 0.380$), location (F2, 25=0.39, $P = 0.684$), and percent overlap (F2, 25=0.20, $P = 0.818$) of use-areas of radio-marked female deer did not differ between during- and after-treatment periods.

In Gilsdorf *et al*.,[25] the use of frightening devices in wildlife damage management was also presented. This paper was motivated by the need to device a type of stimuli that can serve as a frightening device in wildlife management. The objective was to develop bioacoustics device that can handle habituation. To carry out the objective in this paper, animal activated methods were used, and the methods used to delay habituation included changing the location devices and altering the periodicity of stimuli or the use of a combination of devices. Notable limitations with these methods were the time consumption, which was undesirable in efficient agricultural production, and gas exploders, which also disturbed nearby residents due to high noise levels. In most cases, these frightening devices are non-specific, making it possible for any animal to activate them, and not only by the target species. This increases the risk of habituation. A more frequently used non-invasive technique for behavior recognition is video recordings.

In video recordings, digital image processing techniques and tracking algorithms can be utilized to detect and recognize specific movements [Table 1], which are linked to certain behaviors. Compared to acoustics measurements, the range of visual information may be lower. However, the link between visual information, like movement or posture, and behavior is more straightforward. More domain-related applications include monitoring of livestock behavior, including cows.[27] These applications are either focused on controlled experiments or indoor applications, which is not the case with wildlife in an agricultural setting. Most studies conducted on new technology GPS collars have examined location accuracy; two-dimensional (2D) versus three-dimensional (3D) locations, factors affecting accuracy and success rate, and performance under various cover types. Evaluation and testing are important because researchers require some level of confidence in a new system before general technology adaptation.[28]

For open canopy conditions, uncorrected readings from a GPS collar had a 50% circular error probable (CEP) of 28.2 m and a 95% CEP of 73.7 m.[29] These same readings with differential GPS (DGPS) gave values of 4 m at 50% CEP and 10.6 m at 95% CEP. Noted also was that accuracy was not affected by heavy rain. Under open canopy 95% of uncorrected readings had errors <125.6 m.[30] With DGPS, the 95% CEP was reduced to 7.5 m. Increased time-to-location fix with increased density of forest cover is shown in Moen *et al*.[31] In Rempel and Rodgers,[30] decreased accuracy of both DGPS and non-DGPS locations with increased canopy cover was verified. Furthermore, demonstrated, in Rempel and Rodgers[30] reduced rate of successful GPS location fixes with increased density of tree cover. The overall success rate of signal acquisition has increased from 71% to 89%.[32] Studied in Moen *et al*.[31] were moose movement and habitat use on collar performance to assess the effects of a GPS receiver collar being worn by an animal.

No correlation was found between moose movement and any of the following: Proportion of 2D, 3D, or failed location attempts; time to location fix; and higher dilution of precision for either 2D or 3D locations.[31] Observed in Moen *et al*.[31] was that fix success rate was related to ambient temperature where moose use cooler, denser vegetation in warmer weather. GPS and GIS Applications in Domestic Animal Research Limited studies have examined GPS receiver performance on animals, mostly wildlife in the field. One study in Wales tracked sheep with GPS to correlate higher cesium levels in carcasses of animals that had grazed in specific areas,[33,34]

Table 1: Overview of active animal detection based on image processing (Depu Zhou, 2014)

Year	Reference	Techniques	Advantages	Disadvantages
2006	[36]	Haar-like features based on AdaBoost and image feature-based tracking	Real time Smooth and accurate Tracking included	Some false positive Only focus on face detection
2009	[37]	Background subtraction method after getting the background image	Very fast Can detect any kind of animals	The background must be stable Cannot work as an on-vehicle system
2011	[38]	Haar of oriented gradient	Various animal head (cat, fox, panda, wolf, etc.)	Slow Only front face
2012	[39]	Thermal camera and GNT + histogram of oriented gradients	Fast to get region-of-interests High detection rate Plenty of deer postures included	Only deer detection Cannot work in strong light intensity environment Misidentification (car, human)
2013	[40]	2-Stage: Local binary pattern + AdaBoost and histogram of oriented gradients + support vector machine trained by separate databases	Real time Variety of animals Low false positive rate Different weather conditions	Only consider two types animal postures
2017	[41]	Convolutional neural network	The best experimental results of animal recognition were obtained using the proposed convolutional neural network The experimental result shows that the LBPH algorithm provides better results than principal component analysis, linear discriminant analysis, and support vector machine for large training set On the other hand, support vector machine is better than principal component analysis and linear discriminant analysis for small training data set	Reliability of the methods on larger databases of animal images was not carried out Experiments with the methods on other animal databases were left as future work

Success in tracking was obtained at the expense of a bulky pannier pack on each animal. Before DGPS, 95th percentile errors were 57.8 m. After DGPS, errors were within 3.9 m of true location. The authors commented that "GPS with differential correction is the only existing tracking/navigation system which has the potential to meet (horizontal accuracy) requirements." Reported in Hulbert *et al*.[35] was that 8 of 16 Scottish Blackface ewes were fitted with GPS collars weighing 863 g, representing 2.2% of body weight. No differences between circadian rhythm and bite rate were found between the two sets of animals.

GPS for animal monitoring

Navstar GPS (Navigation System with Timing and Ranging) is operated by the US Department of Defense. Initially designed for the military, users obtain position fixes through a constellation of carefully monitored earth-orbiting satellites. The GPS system components are: (1) Space segment – 24 satellites arranged in orbits where five to eight satellites are visible from any point on earth at any time and generate/transmit precisely timed radio signals; (2) control segment – network of ground-based stations to monitor satellite information (health status and time, and satellite location) to ensure correct operation of the system; and (3) user segment – user-community receivers that convert satellite signals into location estimates. Apart from receiver cost, processing equipment or software, there is no subscription cost involved with using basic GPS signals.[28]

Veracity of GPS technology

In Turner *et al*.,[28] while GPS uses extremely accurate timing mechanisms and state-of-art electronics, it is subject to errors, notably:

- Satellite clock errors – system depends on accuracy of satellite clocks
- Satellite position errors – known as ephemeris errors
- Receiver errors – accuracy of clock
- Atmospheric errors – propagation rates of radio waves change as they move through ionosphere and troposphere
- Multipath errors – radio signal reflection off large objects
- Selective availability (SA) errors – degraded accuracy of clock and ephemeral correction information is biggest component of error for civilian users.

This deliberate and unpredictable waver of the satellite clock (controlled by the military) can be switched on or off at will. The SA results in decreased accuracy of location and are intended to prevent more accurate positioning capabilities from falling into enemy's hands. This inaccuracy can be vastly improved with DGPS correction procedure. A stationary receiver (base station) is placed at a surveyed mark and takes position readings simultaneous with a roving receiver. The stationary receiver calculates location positions that will not correspond exactly to the surveyed mark due to the error sources. However, since the stationary marker has known coordinates, the receiver can calculate the magnitude of errors involved. If the roving receiver is relatively close to the base station (within approximately 50 km), many of the same errors also apply to the roving receiver and can be removed from location fixes. In this way, an accuracy of at least 5 m horizontal is readily obtainable. Absolute errors are expressed as radial distance of error location from true location. CEP is circle radius that contains the stated percentile of points around a true location. [29,30,32] The 95% CEP value is determined by graphically locating all data points located in the 95th percentile.

GPS location veracity on animal

Most studies conducted on new-technology GPS collars have examined location accuracy, 2D versus 3D locations, factors affecting accuracy and success rate, and performance under various cover types.[28] Evaluation and testing are important because researchers require some level of confidence in a new system before general technology adaptation. Reported in Moen *et al*.[29] was that, for open canopy conditions, uncorrected readings from a GPS collar had a 50% CEP of 28.2 m and a 95% CEP of 73.7 m. These same readings with DGPS gave values of 4 m at 50% CEP and 10.6 m at 95% CEP. Furthermore, noted in Moen *et al*.[29] was that accuracy was not affected by heavy rain. Found in Rempel and Rodgers[30] was that under open canopy 95% of uncorrected readings had errors <125.6 m. With DGPS, the 95% CEP was reduced to 7.5 m. Showed in Moen *et al*.[31] were increased time-to-location fix with increased density of tree cover.

Verified in Rempel and Rodgers[30] were decreased accuracy of both DGPS and non-DGPS locations with increased canopy cover. Also demonstrated was a reduction in the rate of successful GPS location fixes with an increase in density of tree cover.[30] The overall success rate of signal acquisition has increased from 71% to 89%.[32] Presented in Moen *et al.*,[31] were the effects of moose movement and habitat use on GPS collar performance to assess the effects of a GPS receiver collar being worn by an animal. No correlation was found between moose movement and any of the following: Proportion of 2D, 3D, or failed location attempts; time to location fix; and higher dilution of precision for either 2D or 3D locations.[31] Observed in Moen *et al.*[31] was that, fix success rate was related to ambient temperature where moose uses cooler, denser vegetation in warmer weather. GPS and GIS Applications in Domestic Animal Research Limited studies have examined GPS receiver performance on animals, mostly wildlife in the field. One study in Wales tracked sheep with GPS to correlate higher cesium levels in carcasses of animals that had grazed in specific areas.[33,34] Success in tracking was obtained at the expense of a bulky pannier pack on each animal.

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MATERIALS AND METHODS

Article resources included paddock [Figure 1] three cattle, three waterproof GPS tracking collars (TR20) for cattle [Figure 2], and supporting application software by Sigfox's global Internet of Thing (IoT) network. The rectangular paddock [Figure 1] was 121 by 174 m. Forage was predominantly agricultural plants. Cattle weighing up to 580 kg were used. All data collections were initiated with the collared cattle. Location information (latitude and longitude) was stored cumulatively in on-board memory sufficient in size for position fixes. Each fix record contained corresponding height estimate, GPS date and time, dilution of precision value, fix status, temperature, and plus vertical and horizontal activity sensor counts in fixed intervals. Collar units were compact, robust, and lightweight <1 kg. Figure 2 illustrates a GPS collar on cattle in the paddock.

Collar was fitted with additional sensor types: (1) A temperature sensor records temperature per GPS location fix. The sensor is not directly exposed and may display lag time in response to rapid temperature changes. (2) Dual-axis motion sensors record animal movement and are sensitive to horizontal and vertical movements of the head and neck. They record activity in movement counts that are stored with other information when GPS position fix is taken, then are reset to zero. The time period during which sensors record movement during each fixed interval are user-defined. Two-way data transfer between the collar unit and the smartphone was facilitated by a network of Sigfox's unique network dedicated entirely to the IoT.

This secure, global network was built specifically to power smart devices. Unlike most first-generation smart applications, devices that connect to the Sigfox network do not rely on WiFi or 4G networks, making the device ideal solution and real "real time" monitoring device. TR20 GPS tracking collar is plug-and-play, so pairing or complex configuration is not required and can be connected to the network in a matter of minutes. Once connected, each device gathers real time information on the location of an animal, as well as the animal's speed, body temperature, and stress level. This information is transmitted to the internet and made available in a user-friendly way to herdsmen on smart phone, tablet or desktop computer. Alert notifications are sent if animal strays beyond set boundaries, or if any behavioral anomaly occurs. Collar attachment on cattle was accomplished within a few minutes while the cattle were confined in a squeeze chute. Data collected from GPS collars were manipulated using the

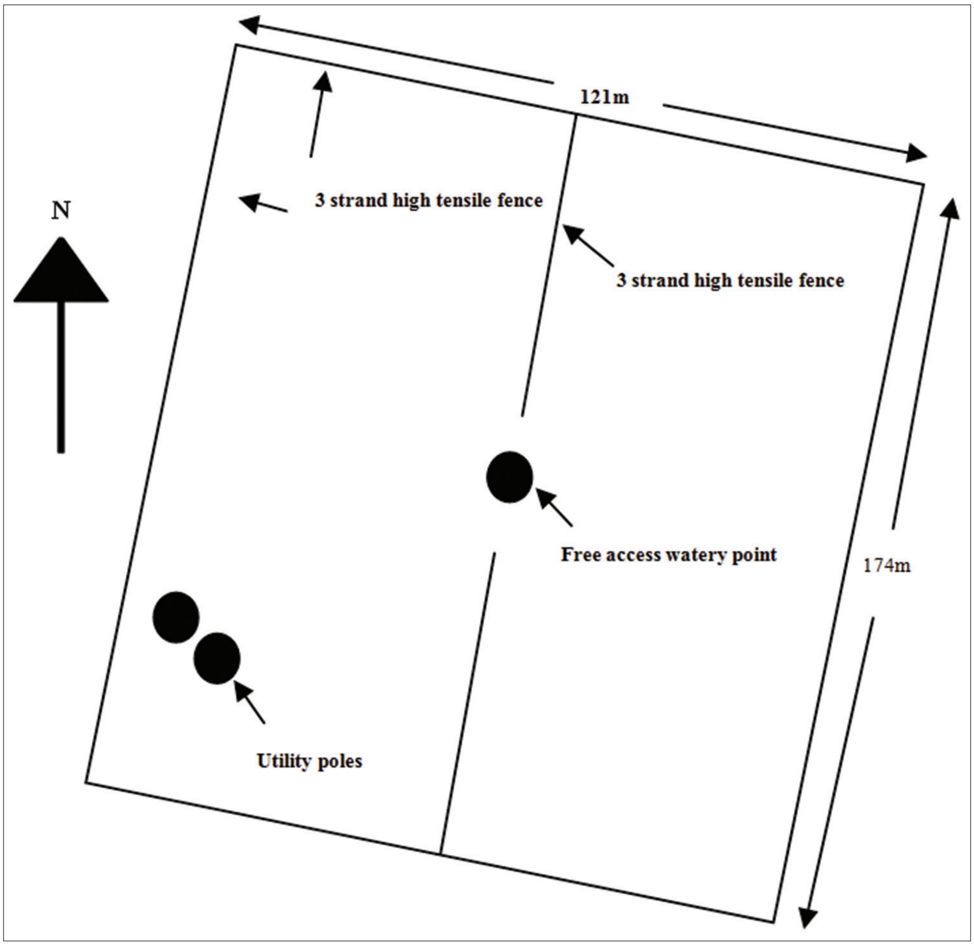

Figure 1: Diagram of paddock layout (Adapted from Turner *et al*., 2001)

Figure 2: Cattle equipped with a collar-mounted global positioning system device

proprietary program designed to differentially correct position fix data for increased accuracy. Data were collected from a collar (October 2018) to assess static accuracy.

The collar was placed and centered 1m above a known longitude/latitude benchmark. Readings were taken at 5 min intervals for 24 h. Statistical analysis (CEP) was applied to determine error-of-location estimates. Three cattle data collections were conducted: (1) November 2017; (2) May 2018; and September 2018. The GPS fix interval was set at 5 min for each data collection. Pasture utilization, measured by time spent in each paddock grid section, was used as comparative measure between different collar strategies. Utilization per cell was indicated by number of locations (GPS fixes) within cell multiplied by GPS fix interval. Cell utilization was determined for period and expressed as a percentage of total paddock occupancy time. This percentage was used to compare among cells the effect of different GPS fixed intervals or optimum number of animals collared. Five minutes fixed interval utilization percentages were considered the control value against which other fixed intervals were compared. Previously, collar capabilities were limited to animal location without indication of active grazing. The GPS location fixes were taken every 5 min for 7 days where the activity-sampling window was set at 4 min between fixes. Cattle were distantly observed on two occasions, each lasting up to 8 consecutive h. At each GPS location fix, the general behavior of each cattle during the preceding 5 min was classified as active (grazing) or inactive (standing or lying). Counts from horizontal and vertical activity sensors were summed for respective 4 min observation windows and data were analyzed for differences between collars and observed activity per period. An activity counter cutoff value was determined through trial and error that classified the activity of animals. These data were checked against observed data to evaluate the accuracy of this approach. To the very stubborn cattle, a little higher level of irritation to change their behavior was using VF as illustrated in Figure 3.

As cattle move toward the virtual fence perimeter, it goes from a very benign to a fairly irritating set of sensory cues, and if they are all on at their highest intensity, it is very irritating. As the cattle approach a virtual fence boundary, we send the cues on the acute side, to direct it away from the boundary as quickly and with as little amount of irritation as possible. If we tried to move the cattle by cuing the obtuse side, it would have had to move deeper into the irritation gradient before being able to exit it. We do not want to overstress the animal. Hence, we end up, either in distance or time or both, having a point at which, if this animal decides it really wants what's over here, its not going to be irritated to the point of going nuts. We have built-in, failsafe ways that, if the animal does not respond appropriately, we are not going to do anything that would cause negative animal welfare issues. The VF works like an adaptive system; adaptive system is a set of interacting or interdependent entities, real, or abstract, forming an integrated whole that together are able to respond to environmental changes or changes in the interacting parts, in a way analogous to either continuous physiological homeostasis or evolutionary adaptation in biology. The highly accurate GPS tracking included in cattle collar enables boundaries to be set on an app-based satellite map. This allows boundaries to be changed remotely at any time. If any cattle stray outside the boundaries, an alert is triggered in the app and GPS tracking device is activated on the animal's collar.

VF is analogous to adaptive system, in the sense that every adaptive system converges to a state in which all kinds of stimulation ceases.[39] Mathematically, given a system *S*, we say that a physical event *E* is a stimulus for the system *S* if and only if the probability $P(S \rightarrow S'|E)$ that the system suffers a change or be perturbed (in its elements or in its processes) when the event *E* Eoccurs is strictly greater than the prior probability that *S* suffers a change independently of *E*:

$$P(S \rightarrow S' \mid E) > P(S \rightarrow S') \quad (1)$$

Let *S* be an arbitrary system subject to changes in time *t* and let *E* be an arbitrary event that is a stimulus for the system *E*: We say that *S* is an adaptive system if and only if when *t* tends to infinity $t \rightarrow \infty$ the probability that the system *S* change its behavior $(S \rightarrow S')$ in a time step t_0 given the event *E* is equal to the probability that the

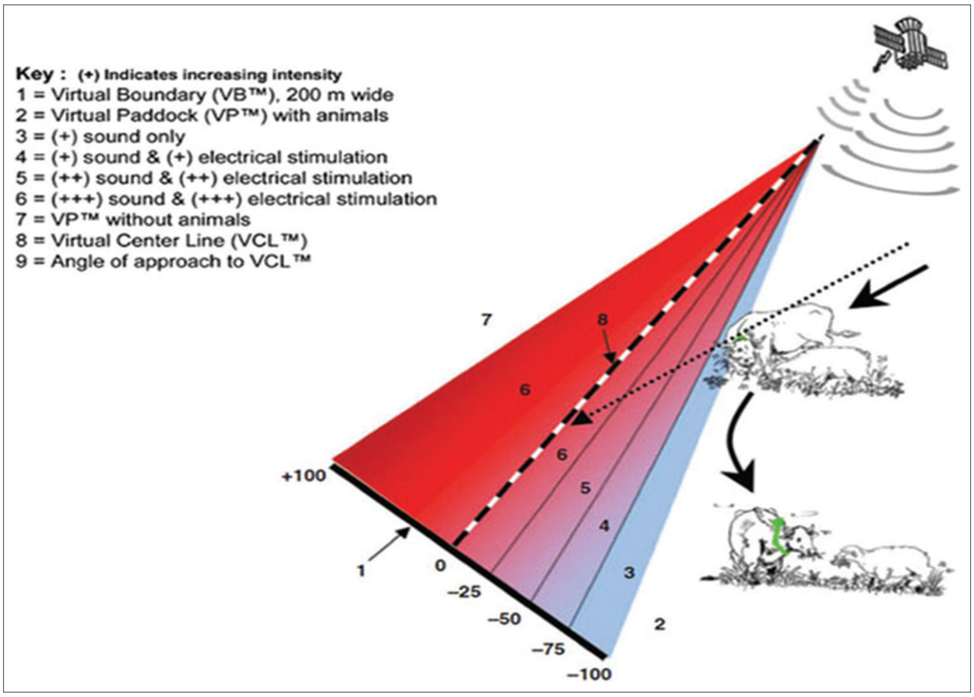

Figure 3: Diagram showing how directional virtual fencing operates (Dean M. Anderson's 2007 paper, "Virtual Fencing: Past, Present, and Future")

system change its behavior independently of the occurrence of the event *E*. In mathematical terms:

$$-(_{t0}\ (S\rightarrow S' \mid E)>P_{t0}\ (S\rightarrow S')>0 \quad (2)$$

$$-\lim_{t\rightarrow\infty} P_t\ (S\rightarrow S' \mid E)=P_t\ (S\rightarrow S') \quad (3)$$

Thus, for each instant *t* will exist a temporal interval *h* such that:

$$P_{t+h}(S\rightarrow S' \mid E)-P_{t+h}(S\rightarrow S')<P_t\ (S\rightarrow S' \mid E)-P_t\ (S\rightarrow S') \quad (4)$$

From the above equations, it is seen that an adaptive system must be able to alter the periodicity of stimuli and make it possible to utilize a combination of stimuli. When frightening stimuli are based on bioacoustics, for example, the system should be able to detect and recognize specific species. Thereby, the stimuli can be targeted toward these species most effectively. Furthermore, as presented in Bello,[40] de Lope and Maravall,[41] the device should enable reinforcement if needed. Applying this to Figure 3, the black-and-white dashed line (8) in Figure 3 shows where a conventional fence would be placed. A magnetometer in the device worn on the cattle's head determines the animal's angle of approach. A GPS system in the device detects when the animal wanders into the virtual boundary band. Algorithms then combine that data to determine which side of the animal's to cue, and at what intensity.

RESULTS AND DISCUSSION

Testing showed that location fixes over a 24 h period were accurate at approximately 8 m 95% of the time after differential correction. Errors had no directional bias, which is consistent with the findings of other studies. Increasing GPS fix interval from 5 to 30 min introduced proportionally increasing errors compared with original 5 min results [Table 2]. However, errors were small (approximately 7%) for a GPS fix interval of 30 min with a single animal. Errors introduced for multiple animals collared (4%) are approximately two-thirds that of a single animal. Significant errors were introduced when fewer collars were used to model locations of more animals [Table 3]. These errors ranged from 10% when two of three cattle were collared compared to nearly 40% when only one of three cattle was collared.

Table 2: Percentage error for single animal and herd (3 herd, in bold) paddock cell use with increasing GPS fix intervals

GPS fix interval, min			
Test date	5	10	15
November 2017	0	1.9	3.5
	0	**0.4**	**1.3**
May 2018	0	1.4	2.4
	0	**0.7**	**0.7**
September 2018	0	0.9	2.8
	0	**1.6**	**1.7**
Average	0	0.9	1.2

Table 3: Average percentage error associated with paddock cell use as number of collars/herd (3 head) is reduced

Number of collar	Error	Range
Three	11.9	10.0
Two	13.3	11.5
One	28.4	12.4

Table 4: Estimated percentage of time spent grazing for each collar-September 2018

Collar number	Percentage of time spent grazing (%)
2	21.3
5	23.3
7	22.4

The range of error was approximately 70% of the average error values, indicating large animal variability. When fewer collars were used, average error and range of error increased. Expressed animal individuality yielded unique individual tracking patterns in the relatively small, intensively managed paddock. Behavior differences were found between collars for activity sensor counts for the same observed behavior. This implies that mounting of collars per animal should be standardized (freedom of movement) and that individual collars may need to be calibrated. However, observed active versus inactive sensor count means were different, suggesting that successful classification of activity counts occurred.

Animal sensor count sums (during 4 min periods between GPS fixes) <100 were classified as inactive, while sums equal to or greater than 100 were regarded as active. This system correctly classified 94.8% (128/135) of active (grazing) data records, and 91.2% (1092/1196) inactive (not grazing) data records for an overall performance of 91.7% (1220/1331) of records correctly classified. This high percentage of correct classification imparts confidence that accurate prediction of animal activity was accomplished. Grazing location fixes in active classification were relatively well distributed. Inactive fixes (lying and standing behavior) were clustered, located near water or in favorite resting places. Active versus inactive classifications in data were used to estimate the amount of time of "grazing" for each animal [Table 4].

CONCLUSION

As there are different species of animal, so also there are, different behaviors exhibited by these animals. The behavior of livestock, wild animals, and domestics animals are not the same. Moreover, the taxonomy of animal does not guarantee the same behavior from these groups. This is a challenge for monitoring and adaptive frightening devices to adapt to the behavioral changes exhibited by these animals. Both acoustics and bioacoustics methods of frightening animals were seen as weak methods due to the habituation of animals to them after some time. However, if combined, these methods are seen as breakthrough in overcoming the habituation exhibited by animals. Animal tracking and monitoring technology, on the other hand, have progressed dramatically in the past few years. Progress from RFID, to biometrics-based identification, to satellite-based systems such as Navstar GPS has been dramatic. The use of each system is associated with strengths and weaknesses; however, the GPS system either matches or surpasses the strengths of any other method, with few weaknesses. An interesting thing worthy of emphasizing in the course of this article is that, with the application of GPS and VF, one can encompass a vegetation situation, change the behavior of the very stubborn cattle, virtually monitoring cattle to restrict their movement or whatever, much better than one can if one has to build a conventional fence or use traditional methods of identifying and monitoring cattle. This technology could profoundly reshape our relationships with domesticated animals, the landscape, and each other. Parts of the benefits of GPS and VF in monitoring cattle are: (1) GPS collars gather valuable information about animals in a herd; and (2) they also enable powerful analysis of this information. Information from this collar is transmitted to a mobile app, using Sigfox's global IoT network. Once there, the app uses behavioral algorithms-customized for cattle to analyze data from each animal's collar in real time. Alerts are triggered if unusual behavior occurs, such as a drop in temperature, a change in movement patterns or going outside boundaries. In addition, to help identify identification and monitoring issues in real time, GPS cattle collars aggregate all of the information they gather, storing it in a user-friendly database. This comprehensive set of information gives users a powerful tool to help make long-term herd management decision. Data can be accessed about individual animals or the herd as a whole. Graphs and reports chart movement patterns, grazing routes, activity distance traveled, and the time spent resting. Maps show routes traveled by animals during a given time period. The view in Turner *et al*.[28] that, utilizing real time GPS location fixes for management would for sometime be a challenge because of the non-existence of the technology in a differentially corrected real time form for animal tracking, is now a thing of the past with the innovation of IoT-based GPS animal tracking devices.

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