TRACKING ANIMALS WITH GPS

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VIRTUAL FENCING - A PRESCRIPTION RANGE ANIMAL MANAGEMENT TOOL FOR THE 21ST CENTURY

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ABSTRACT

Managing free-ranging animals to utilize forage resources efficiently remains a worldwide challenge as we enter the 21st century. Optimum forage utilization requires herbivores be periodically moved commensurate with the landscape's productivity. Stationary conventional fencing in the form of wood, wire or stone has been tried alone and in combination with many other tools and techniques to positively affect animal distribution and forage utilization, yet none consistently permit flexible management in real time. Virtual fencing has the potential to automate animal management and provide autonomous animal control in real time. Virtual fencing systems require that animals wear an electronics package that includes hardware, software and an antenna to receive Radio Frequency (RF) signals. A patented virtual fence device will be described that uses RF signals emanating from navigation satellites of the Global Positioning System (GPS). These signals are used to locate the animal's geographic location, which can be logged at programmable intervals of ≥ 1 second. Furthermore, these signals are used to build virtual fences that can be programmed to take any geometrical shape, be manipulated in space and time and can surround areas as well as individuals. The unit's Geographic Information System (GIS) data continuously compares the animal's location and its angle of approach to that of the closest virtual fence. Should an animal attempt to penetrate a virtual fence, algorithms within the unit's central processing unit determine the suite of programmable cues to be applied to either the animal's right or left side to maximize the animal's distance of separation from a virtual fence in the least amount of travel. The cues are applied in a ramped fashion, beginning with the least and progressing to the most aversive, depending upon how near the animal is to the virtual fence. Using this approach, the animal determines the intensity of cuing necessary to elicit a change in its behaviour. However, if the animal fails to respond at the highest level of cuing, the unit has been built to shut down in a fail-safe manner to prevent ineffective and unnecessary stress to the animal. In this device electronic generated audio sound and shock replace visual cues to produce movement. Virtual fencing capitalizes on low stress handling principles, in which the animal's innate behaviour is to move away from a stimulus that has penetrated its fight-flight zone. Recently a prototype device in the form of a neck-saddle was evaluated to establish the proof-of-concept that bilaterally applied cues will change not only a cow's location but also its direction of travel. Preliminary tests suggest virtual fencing will control beef cattle in a humane and reproducible manner. However, more research is required to determine how virtual fencing will optimally benefit resource stewardship, using both domestic and wildlife species. Virtual fencing utilizing GPS technology and bilateral cuing will provide a novel tool for bringing prescription animal management to reality in the 21st century.

Key words: Wireless fencing, Global Positioning System (GPS), Geographical Information System (GIS), livestock, wildlife, animal control

INTRODUCTION

Managing animals has challenged man since the dawn of civilization (Holy Bible). With approximately 4 x 10^9 cattle, sheep, goats, camels, buffaloes, pigs, horses, mules and asses (FAO 1999) on 13 x 10^9 ha of land (FAO 1987) animal distribution remains the second most critical challenge after establishing a proper stocking rate (Holechek et al. 1998; Ratliff 2000). Animal distribution impacts the intensity and frequency of defoliation, which together determine net herbage growth following defoliation and herbage intake during defoliation (Parsons 1988) as well as the landscape's potential for future herbage growth by influencing erosion and the watershed itself (Kauffman and Krueger 1984).

Improving animal distribution (Fig. 1) may increase livestock production yet the additional profit gained may be partially or totally eliminated due to the costs associated with improving distribution (Conner 1991). Fencing is just one approach that has been used to manage animal distribution. This paper focuses on managing free-ranging animals using virtual fencing, a prescription tool to unlock ecologically sound and flexible plant and animal husbandry in the 21st century.

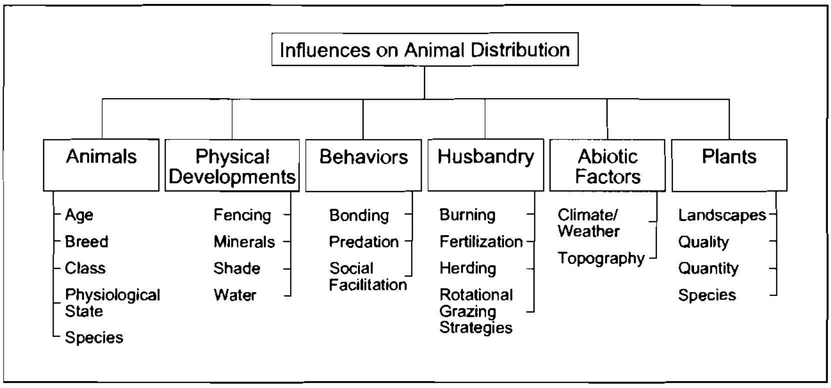

Figure 1 Factors influencing free-ranging animal distribution.

WHAT IS AN INVISIBLE FENCE?

An invisible fence is an electronically generated 3-dimensional boundary that may take any geometrical shape to enclose an area, as well as surround individual animals, but is unseen by the eye. Invisible fences can only control animals that are wearing equipment capable of capturing and using electronic signals. The majority of signals used in invisible fences are radio frequencies (RF) between 3kHz and 300 giga Hz (Yarnall and Yarnall 1996). However, some systems utilize near infrared energy (McCarney et al. 1997) or compressional wave beams (Bianco and Ehren 1997).

Invisible fences use sensory cues other than sight to produce a change in an animal's behaviour. These cues must be aversive enough to cause animals to alter their behaviour through innate instinct and/or training. Using cues to alter behaviours has been investigated under the topic of instrumental animal conditioning (Kimble 1961). Chemoreceptors, mechanoreceptors or thermoreceptors individually, or in some combination, must be stimulated to keep an animal from crossing the invisible boundary. Large animals can be controlled using audio cues in the form of whistles, beeps or a combinations of sounds (Albright et al 1966; Ames and Arehart 1972; Fury 1976; Gonda and Vancuza 1982; Heffner and Heffner 1983; Custer 1995) including the human voice (Yarnell and Yarnell 1996; Kim et al. 1997). In addition, electric shock alone and in combination with audio cues have also been used to manage animals (Miles 1951; Karn and Lorenz 1984; Martin et al. 1989; Gonda and Farkas 1989; McDade et al. 1993; Markus et al. 1998b).

Cues used in currently available invisible fencing devices are not easily changed once established (Touchton and Peinetti 1995) and appear limited to only a few preset levels (Gonda and Farkas 1989). However, most commercial invisible fencing devices contain safety features to prevent inhumane cuing thus promoting optimum animal welfare (Mench and van Tienhoven 1986; Stricklin 1989; Arave and Albright 1998).

The first commercial invisible fencing system was designed for containing pets and was patented in 1974 by Richard Peck, owner of the Invisible Fence® Company (Wayne, PA). His system was also the first system tried on livestock. In 1987 unattended domestic goats were successfully confined on leafy spurge (*Euphorbia esula*) using his electronic dog collar (Fay et al. 1989). Shortly thereafter Quigley et al. (1990) used dog training collars manufactured by Tri-Tronics® (Tucson, AZ) to train steers to avoid a specific area; this was accomplished in less than two days. Recently collars manufactured by Tri-Tronics® were successfully used to control heifers in Canadian field and pen trials (Markus et al. 1998a). Rose (1991) proposed a signal transmitter/receiver system for activating an electronic nose clip to control cattle. Electronic ear tags using audio sound and electric shock cues, manufactured by AgriTech Electronics (Chanute, KS) were evaluated in 1992 in Texas and Nevada and found to be 90% effective in preventing cross bred yearling steers and heifers from entering a zone of exclusion (Tiedemann et al. 1999). In all the livestock trials mentioned the RF signals originated from ground-based transceivers that transmitted unlicenced low power high frequency signals. Such systems would require many transceivers if the topography is undulating and this may be a reason these systems never gained widespread acceptance for managing livestock on large pastures.

THE GLOBAL POSITIONING SYSTEM (GPS)

Many of the line-of-sight limitations of ground-based RF systems disappear when RF signals originate from satellites, such as those of the Global Positioning System (GPS; Hurn 1993; Herring 1996), the Global Navigation Satellite System (GLONASS; Almanac 2000; Krüger et al. 1994; Herring 1996; Langley 1998) or the proposed European public-private Galileo Global Navigation Satellite System (GNSS; Gallimore and Maini 2000). With satellite technology have come devices that can control both animal location and direction of movement (Manning 1998; Anderson and Hale 2001). Though ground-based transceivers are not required, other challenges arise with satellite-generated RF signals, including those from forest vegetation canopy which may (Spruce et al. 1993; Rempel et al. 1995) or may not (Bennett et al. 1997; Biggs et al. 1997) affect the signal's reception.

Technically, GPS is simple in concept but incredibly complex in implementation. The current GPS system was not fully operational until the 1990's even though it was developed in the late 1960's and early 1970's for precise timing and space-based navigation by the US Navy and Air Force, respectively, (McNeff 1999). World-wide geographic locations are available from the 28 GPS satellites or 9 Russian GLONASS satellites (Almanac 2000). The GPS satellites circle the earth twice each day (11 hr 58 min/orbit) at an altitude of about 20,000 km in one of six orbits at an inclination of 55° (Krüger et al. 1994). To obtain very precise and accurate locations, a minimum of four satellite signals must be available (Hurn 1993). Prior to 12:00 A M on May 2, 2000, the signal available to commercial users had been distorted by the military for security reasons. This distortion was known as selective availability (SA) and limited civilian accuracy to no more than ± 100 m (Lang 1997). Removal of SA improved accuracy to ± 20m (Anonymous 2000; Divis 2000). For higher accuracy Differential Global Positioning Systems (DGPS; Hurn1995; Moen et al. 1997) technology can be used.

The first study that employed GPS to locate animals was begun in March 1994 using collars designed and manufactured by Lotek Engineering Inc. (Newmarket Ontario, Canada; Rodgers and Lawson 1997). To date GPS systems have been used to successfully track domestic sheep (Roberts et al. 1995; Rutter et al. 1997) and cattle (Udal et al. 1998; Udal et al. 1999) as well as numerous wildlife species (Austin and Pietz 1997) to accuracies never before possible (Tomkiewicz 1997). Recently shock collars for training dogs (Files 1999) and devices to control large animals (Marsh 1999; Anderson and Hale 2001) have incorporated GPS technology.

THE FIGHT-FLIGHT ZONE

The key to controlling animals using invisible fencing is to administer appropriate cue(s) at the appropriate time and in the appropriate location and then stop the cue(s) immediately when the appropriate behaviour occurs. The basis for knowing when, where and how much cuing is required lies in the principles of low stress animal handling practices, as advocated by applied animal ethologists including Bud Williams (personal communication), Smith (1998) and Grandin (1999).

All animals have a fight-flight zone or region surrounding the animal that, when penetrated, causes the animal to move. Fight-flight zones are totally dynamic and constantly changing in size and shape over time even for the same animal. Animals that have had their fight-flight zone penetrated on their left side normally move to the right and vice versa. This innate behaviour to move away from a novel cue, regardless of type, is the most common instinctive initial defensive gesture shown among all animals (Dusenbery 1992; Smith 1998) and forms the basis by which animals are controlled using bilateral virtual fencing.

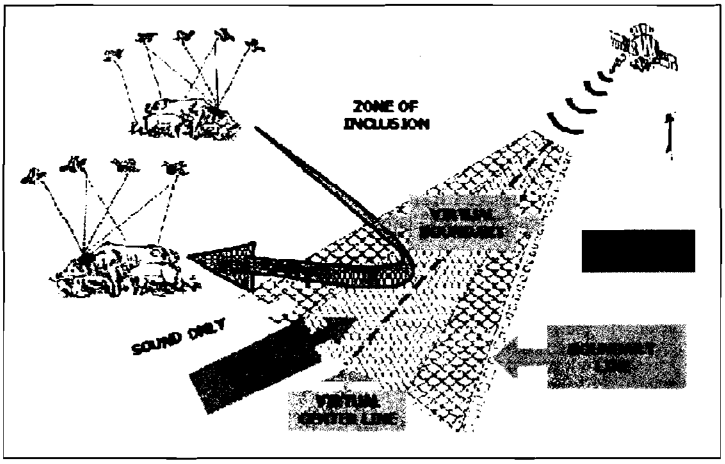

Figure 2 Hypothetical pastoral scenario for controlling free-ranging animals with a patented (Anderson and Hale 2001) virtual fencing device that uses autonomously applied bilateral cues. Radio Frequency (RF) signals from Global Positioning Satellites (GPS) are used to determine the geographic location of the instrumented cow and bonded sheep (Anderson 1998) and calculate their distance and subsequent angle of approach to the nearest ***virtual boundary****. Geographic Information System (GIS) software contained in the neck-saddle determines when the cow has penetrated the* ***virtual boundary****, sensory cues are then administered to the side of the animal to move it back into the* ***zone of inclusion*** *with the least travel and stress. The* ***virtual boundary*** *consists of belts in which a suite of sensory cues (****sound only*** *and* ***sound + shock****) are administered depending on the distance the cow is from the* ***virtual center line****. The cuing characteristics and belt widths are fully programmable. Built in safety features prevent inhumane cuing as well as algorithms for administering sensory cues to turn the animal back toward the* ***zone of inclusion*** *should the animal cross into the* ***zone of exclusion****. The* ***virtual center line*** *can deviate from the* ***boundary line*** *used initially to establish the* ***virtual center line*** *by ± 10 to 25 m using commercial GPS equipment (Shaw et al. 2000).*

WHAT IS BILATERAL VIRTUAL FENCING?

The virtual fence with electronically generated bilateral cuing capabilities involves a patented (Anderson and Hale 2001) method (Fig. 2) and prototype apparatus (Fig. 3). Virtual boundaries of various shapes can be created that are movable in time and space and can be created around individual animals as well as delineating areas using RF signals from GPS satellites. The invention controls animal location and direction of movement using several characteristics not previously available in other invisible fencing systems. First, stimuli are applied bilaterally and autonomously using the RF signals emanating from GPS satellites. With this technology animals can be located as well as having their direction of movement controlled. Second, the cues (audio sound and electric shock) are programmed to ramp in a stepwise fashion, beginning with faint sounds and or small electric shock which would feel like a tingle. These cues are then programmed to progress to much louder sounds and or electric shock similar to that found in devices marketed for managing large animals. Electric shock is only administered if movement of the animal in the appropriate direction has not been detected by the system's microprocessor, following application of the sound cue(s) that cover a variable range of frequencies to accommodate various hearing abilities. If, after applying electric shock, the animal still refuses to change location within a programmable time or distance, the unit will automatically shut down preventing undue stress to the animal. The repertoire of available cues provides a wide range of stimuli to which an animal can react, allowing the animal to choose the appropriate level of stimulation to get movement to an appropriate location where cuing stops. Third, cues are fully programmable making it possible to have different cues on the right side compared to the left side.

The current prototype virtual fencing device is housed in a neck-saddle that attaches to the animal's neck with adjustable belting (Fig. 3). The electronics compartment located atop the saddle positions the GPS antenna skyward, contains the battery necessary to provide power and houses the microprocessor that is the heart of the system's autonomous functioning. An RF transponder allows interfacing or communicating with similar devices worn by other animals or with a central microprocessor. The microprocessor includes hardware and spatial coordinate system software for determining the direction and bearing of the moving animal and comparing this with the position of the predetermined virtual boundaries using Geographical Information System (GIS; Muehrcke and Muehrcke 1998) data. Once the closest virtual boundary and the distance the animal is from it is known, the side of the animal closest to a virtual boundary is determined together with information on whether the animal has penetrated the virtual boundary. If penetration has taken place, a control signal is initiated for activating the appropriate suite of cues to the appropriate side of the animal. The GIS system also stores sensor data, GPS data, system parameters as well as an operating system for scheduling software functions including driver routines for the device's peripherals. This capability allows the user to download specific positions (*i.e.*, GPS coordinates) for desired virtual boundaries and upload all logged sensor and GPS data, in order to change the characteristics of the applied stimuli, and/or reprogram the embedded computer system parameters. Logging the animal's geographic location is programmable at intervals of ≥ 1 second. On either side of the neck-saddle an acoustic piezo transducer and a pair of spring loaded electrodes, located in the neck region proximal to the head and ear, deliver the sound and electric shock to the right and left sides, respectively. The electric shock can be administered either in the presence or absence of sound depending on how the device is programmed.

Determining to which side of the animal the cue(s) are to be applied, is based upon the animal's position with respect to the virtual boundary, the angle of incidence between the animal's direction of travel and the virtual boundary, and the animal's expected response to the bilateral stimulation. If the animal is within the area of inclusion and the angle of incidence is acute then the cue will be applied on the side of the animal that will move the animal into the obtuse angle it forms with the edge of the virtual boundary (Fig. 2). If the animal has penetrated through the virtual boundary and is in the zone of exclusion, the cue(s) will be directed to the obtuse angle. Algorithms in the microprocessor determine to which side the cue(s) should be applied in order to maximize the separation of the animal from the virtual boundary with the minimum change in the animal's bearing. If the animal has penetrated the virtual boundary approximately perpendicular in its movement or the approach is towards a right angle corner of two virtual boundaries the side to which the cues are applied is determined entirely randomly by the microprocessor.

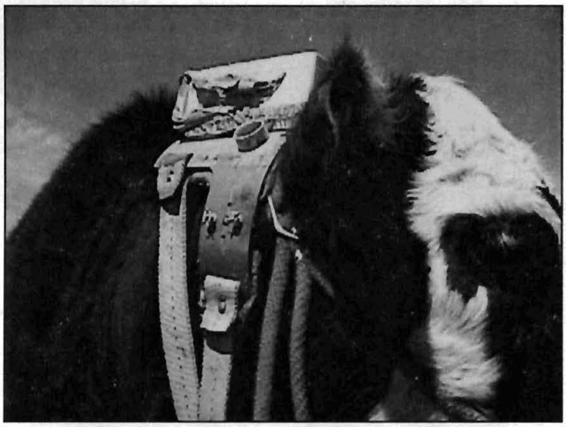

Figure 3 *Virtual fence device housed in a neck-saddle worn by a haltered cow. Above the front strap securing the neck-saddle around the animal's neck are a pair of horizontally-spaced, spring-loaded electrodes for administering electric shock cues to the animal's right side and directly above them is the peizo transducer, housed in a protective cylinder, for producing audio sound cue(s). Electronic hardware and software, with batteries for power, are housed in the rectangular box sitting on the saddle.*

MORE ABOUT SENSORY CONTROL

Conventionally we get animals to do our bidding on our time schedule. This is evidenced by the physical characteristic of many fences and the egos of those who built them. However, for virtual fencing to be used optimally a paradigm shift in thinking will be required to allow the animal to meet our goals, but on their time schedule. Patterns of movement vary among species as well as seasonally and diurnally, due to a number of environmental as well as physiological factors (Arnold and Dudzinski 1978). These factors must be considered in order to determine the optimum time, location and duration to apply cues. Generally the least amount of force required to get an animal to change its location would occur when the animal is already moving and not at rest (Fig. 4). Therefore, cuing only moving animals will probably produce the most efficient and least stressful virtual fence control protocol.

Even with this protocol, virtual fences could potentially pose some challenges since animals are aware of their surroundings (Piggins and Phillips 1998; Veissier et al. 1998). Canadian research found that animals would not penetrate an invisible boundary for up to four days following removal of the controlling cues (Markus 1998a). This suggests that animals may have associated the cue(s) with various landscape objects at the time that the sensory cue(s) were being applied. Using ramped cues and possibly randomly moving the virtual boundaries periodically, may keep animal's focused on the cues rather than on associated objects, but this hypothesis awaits scientific evaluation.

Every animal may not need virtual fencing instrumentation to achieve group control, since domestic mammals evolved from wild species that are social and form groups (Clutton-Brock 1981). Animals that live in groups not only influence one another's diet (Howery et al. 1998) but also their spatial location. Sheep apparently learn to avoid electric fences through social facilitation, since training a few animals appears to affect the entire flock (Lynch et al. 1992). Fay et al. (1989) demonstrated that most non-collared (control) Spanish goats would not stray more than 50 m from collared peers restrained inside RF boundaries. However, as the ratio of collared animals decreased, Fay et al. (1989) found the number of non-collared animal "escapes" increased. Anderson (1998) demonstrated every sheep in a group need not be bonded to cattle if the goal is to have both species of animals remain together in one or more flerds (flocks + herds in which small ruminants have been bonded to cattle; Anderson et al. 1988). Bonded sheep consistently remain with cattle thus eliminating the need for internal conventional sheep tight fencing (Anderson et al. 1994). However, when safety or health issues are the reasons for animal control, systems based strictly on manipulating animal behaviour are not adequate in themselves and conventional fencing should be used.

CONCLUSIONS

Real time autonomous management of free-ranging animal distribution will involve combining cutting edge electronic technology with animal behaviour. Research to address appropriate protocols for managing free-ranging animals with virtual fences has just begun. Virtual fencing will be one of many new tools that combines electronics and animal behaviour to make prescription range animal management a reality in the 21st century.

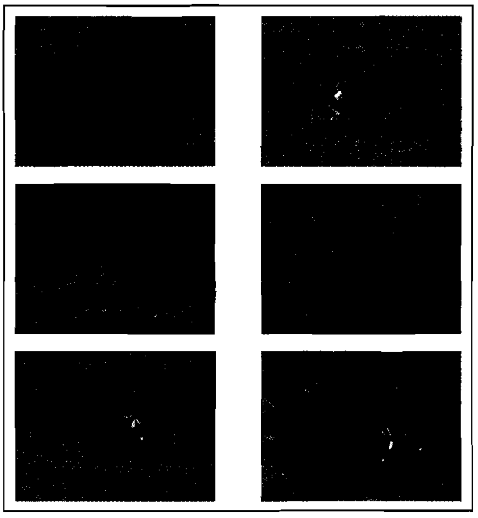

Figure 4 Sequential photos documenting the response of a foraging cow to bilateral cuing from a virtual fence device housed in the neck-saddle. The cow initially grazing south is stimulated on its left side, it turns north (right) and walks away from the cue and subsequently re-establishes grazing in a northerly direction in the presence of two calves.

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