Virtual fence: New realities beyond barbed wire

By Hope A. de Avila, Karen L. Launchbaugh, Krista A. Ehlert, and Jameson R. Brennan

On the Ground

- Virtual fence (VF) is an emerging system to control and confine animals using Global Positioning System (GPS) and communication technologies rather than physical boundaries such as barbed wire or electric fence.
- Animals in a VF system wear a device (e.g., a collar) that emits an audible cue when the animal approaches the virtual boundary and an electrical cue if the boundary is crossed.
- VF provides an adaptive grazing management tool to intensify grazing in some areas or minimize animal use in other areas for specific conservation or production goals.
- Several challenges currently exist with emerging VF technologies and include failure of devices, animals that do not respect the boundary, and excessive time and money to implement.
- VF promises increased flexibility for managing rangelands in response to ecosystem disturbances such as wildland fire, variable forage availability due to climate change, facilitating restoration practices, reducing conflicts between livestock and wildlife, and accommodating human uses on public lands.

Keywords: electronic fences, geofencing, grazing management, precision animal agriculture.

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Introduction

VF is an emerging technology that offers livestock managers a tool to control animal locations without physical boundaries or herders. By using auditory and electrical cues delivered from an animal-borne device, VF can redirect animal movement in accordance with defined electronic boundaries.[1] VF is a potentially transformative technology in rangeland management that could improve the conservation of rangeland resources and enhance livestock production. The ease with which VF may allow managers to establish and remove boundaries for livestock grazing could provide opportunities to address multiple management objectives in a single pasture. For instance, a grazing area may contain greater sage-grouse (*Centrocercus urophasianus)* nesting habitat, a riparian area, a portion of a black-tailed prairie dog (*Cynomys ludovicianus*) colony, and patches of invasive annual grasses, which may benefit from different timing and duration of livestock grazing to achieve intended responses. VF may provide a new and highly malleable way to manage livestock grazing and transform managing livestock distribution on rangelands. Livestock managers need to consider the time and cost to implement, the knowledge to maintain, and the acceptable failure rate of VF. We provide an overview of the concept of VF, its applications, limitations, current knowledge gaps, and future outlook.

The origins of fence

Managing livestock distribution has been a challenge since they were first domesticated more than 10,000 years ago. For most of our shared history, herders and primitive fences constructed from stone and wood were the only means to control livestock movement. The settling of the American West late in the 1800s found homesteaders on the prairies struggling to control livestock without an abundant supply of rock and timber. Initial fence efforts depended on sod, living hedges, and wooden rails to create barriers.[2] These settlers found a solution in a metal wire armed with sharp points called "barbed wire." This iconic wire was introduced in the 1870s and provided a new way to protect crops from livestock by forming property boundaries and essentially ending the days of open range.[3] This pioneering technology generated at least 394 US patents,[4] and there are now >621,000 miles (i.e., 1,000,000 kilometers) of barbed wire fence on rangelands in western United States[5] and millions of miles across the globe.[6]

Electric fence to control livestock was introduced and successfully implemented late in the 1930s in New Zealand by Bill Gallagher.[7] This concept gained traction in the United States in the 1950s and 1960s when it became widely available. Early in the 1960s another New Zealander, Doug Phillips, patented a nonshortable electric fence.[7] This substantially increased the distance electric fence could effectively cover. Today, electrified fence occurs in several forms, including simple metal or high-tensile metal wire and polywire or polytape, which are strands of plastic woven with wire to create cords that carry an electric charge.[8] Innovations to electric fence, like solar chargers, robot deployment, and remote fence-status monitors, have fostered a strong and growing interest in electric fence.[9] Electric fence is highly movable, less expensive, and easier to establish than permanent wire fences; however, it is still labor-intensive, requires regular inspection, and can be difficult to implement on pastures with tall and woody vegetation that can draw down the charge.[8]

The advent of VF

The latest novel development for livestock fencing is called VF, which involves a device worn on the animal delivering auditory and electrical cues to establish virtual management zones. The first successful demonstration of VF was Invisible Fence, which was designed to keep domestic dogs within residential yards.[10] This containment system was developed in 1973 by John Purtell and used a radio signal emitted from a cable buried in the ground to delineate a boundary. A device on the dog's collar delivered an electric stimulus, called a *static correction*, when the dog tried to cross designated boundaries (US Patent No. 3,753,42). In the 1980s, this technology was tested on livestock in a targeted grazing study, and it successfully contained six goats over 12 days in a 70 × 70 m containment area.[11]

When GPS became widely available, Dr. Dean Anderson with the USDA Agricultural Research Service collaborated with a private electronics firm to patent a system where animal location was determined via satellite GPS signals (US Patent No. 6,232,880). In current livestock systems (Fig. 1), animals wear a VF device attached to a collar that delivers auditory cues when the animal is near a designated boundary and electrical cues on a boundary breach. These systems use global navigation satellite systems (GNSS), including GPS and constellations from other countries, such as GLONASS, Galileo, and BeiDou, to determine animal locations. Using associated software, a livestock manager can draw pasture boundaries on a satellite image through a user interface. Boundary amendments or escape notifications are delivered through onsite radio communication base stations or cellular networks.[12]

There are numerous applications of VF technology to achieve production and ecological objectives using grazing livestock. Specifically, VF is applicable across a broad range of landscapes. VF projects have been implemented in every state in the western United States, representing hundreds of thousands of acres of public and private land and thousands of cattle being managed using this technology. Research discussed in this special issue of *Rangelands* spans tallgrass prairies of Kansas and Oklahoma,[13,14] the Northern Great Plains,[15] the Nebraska sandhills,[16] semi-arid rangelands of the southwest,[17,18] and Great Basin landscapes.[19] In addition to the broad-scale applicability across diverse landscapes and plant communities, this special issue also discusses specific considerations when applying VF to manage public lands.

The allure of VF

Many ranchers are enticed by the idea that VF may be a flexible grazing management tool to easily establish and move pasture boundaries. It is likely VF may never replace the need for physical fences along property or unit boundaries. This is in part due to liability concerns with escaped cattle causing property damage or personal injury (e.g., car collisions). In addition, perimeter fences dictate not only property boundaries but also herd boundaries, and effective separation of herds with VF would likely require all landowners within a grazing region to adopt this technology to separate animals among private herds. This is further explored in this special issue because economic analysis on VF versus traditional fencing accounts for the fixed cost associated with perimeter fences under both scenarios.[20] The adaptability of VF will facilitate cross fencing within a unit or pasture. VF systems offer options for landscapes where physical fences would be difficult to construct because of steep or rocky terrain or dense woody vegetation.[21]

VF is often viewed as a desirable option compared to physical wire fence or electric fence in situations where short-term or occasional fences are needed. For example, VF could be used to establish temporary pastures necessary to implement targeted grazing[22] for managing weeds[11] or creating fire breaks.[23] Additionally, the adaptability of VF offers managers the opportunity to implement management-intensive or holistic grazing methods,[21] which rely on high-stock density, small paddocks, and rapid pasture rotations. Furthermore, the technology can be used to reintegrate livestock with cropping systems, where fences are typically absent. This could allow livestock to graze cover crops, crop residue,[24,25] or failed crops for forage.[25]

VF can be implemented to exclude livestock from specific areas or plant communities. This includes riparian zones[26] that are highly attractive to grazing animals, sites at risk for erosion[27] or areas having a high concentration of poisonous plants. It can also be applied to facilitate restoration and revegetation in forest regeneration sites[28] or recently burned areas.[29] It has been suggested that VF could reduce human-livestock conflicts by keeping livestock out of areas with high value to humans such as recreational sites[30] and historically important or archaeological sites. VF could also provide virtual gates to replace the physical wire gates or cattleguards needed where roads cross fence lines. This application of VF could reduce lost livestock and limit negative impacts on grazing management when gates are left open by cyclists, off-road vehicle users, hunters, or other recreationists.[30] A similar application could restrict animal movement across water gaps where fences cross streams or creeks.

VF can enhance habitat quality and minimize obstructions for wildlife on grazing lands. Livestock grazing can benefit wildlife through improved forage quality and yield for species

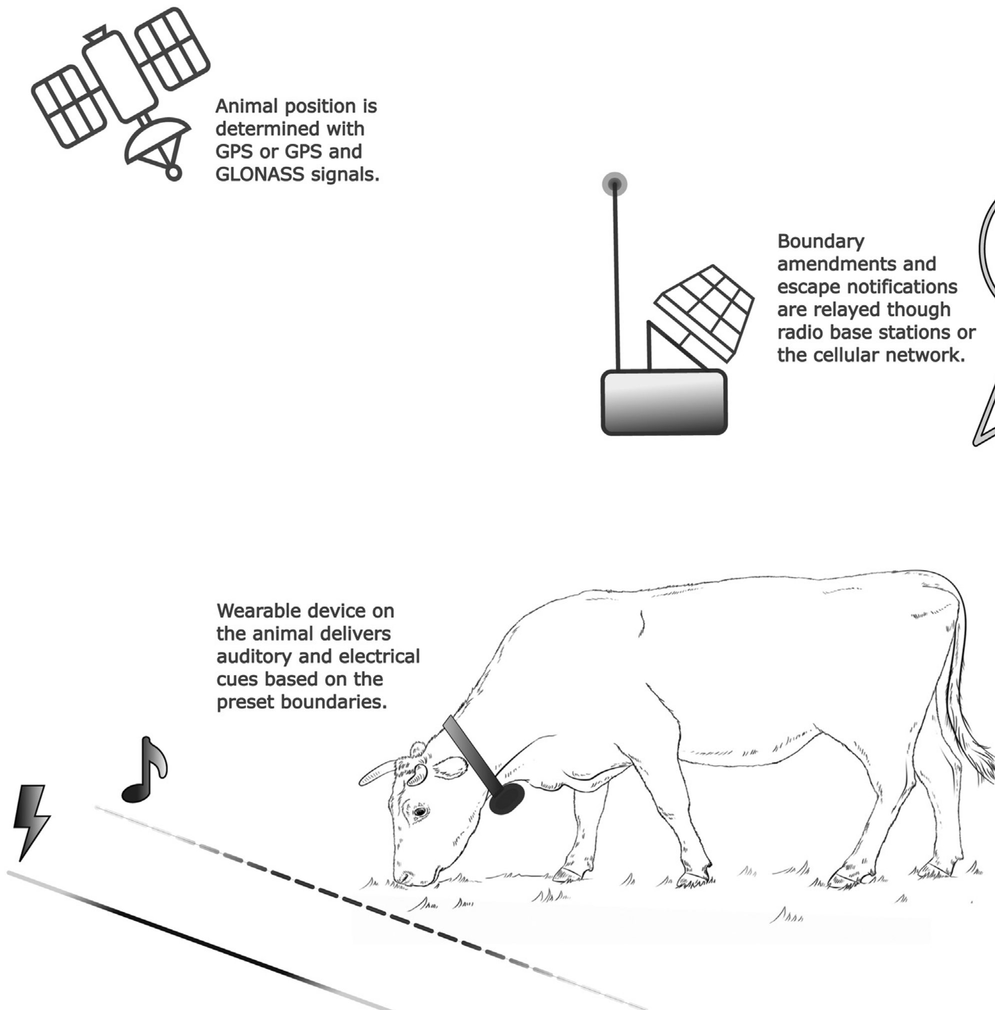

Figure 1. A schematic showing the three-way connection associated with many VF systems. These include location determined by a GNSS, such as GPS or GLONASS, signal, a base station, or cellular network to establish the relationship between animal location and a virtual boundary, and a VF device worn by the animal to deliver auditory and electrical cues based on how preset boundaries relate to current GNSS locations.

such as deer (*Odocoileus* spp.), pronghorn (*Antilocapra americana*), moose (*Alces alces*), and elk (*Cervus canadensis*) or increased preferred forage for quail (*Callipepla* spp. or *Colinus* spp.) and greater sage-grouse.[31] However, physical fences to manage livestock grazing often impair wildlife by disrupting migration routes and causing collisions and entanglement and other habitat disturbances.[32] Wildlife may benefit from VF by using it to control livestock activity in nesting or brooding areas.[33] Similarly, fish spawning grounds could be excluded from livestock access, thereby limiting trampling and sediment disturbance in these areas along a stream.[34] VF could even play a role in minimizing livestock depredation because it would make nonlethal predator management strategies like night penning,[35] tighter animal groups,[36] or hotspot avoidance[35] more feasible especially in remote areas where supplying materials for physical temporary fences would be difficult.

VF technologies, using real-time GNSS tracking, can provide immediate alerts for when animals are outside of pasture boundaries or help in locating livestock in extensive rangeland pastures. Implications for assessing real-time GNSS data to infer forage utilization in time scales relevant to making management decisions are discussed.[17] Further, producers can control subherd groups such as steers and cows in the same pasture or cluster certain cows and bulls together during the breeding season.[37] Several VF systems also allow for the remote herding and gathering of animals.[38]

An important ancillary benefit of VF systems not provided by other types of fence is knowing animal locations. Real-time location information can be valuable to find animals when they have breached a virtual or physical boundary. Furthermore, metrics derived from GNSS to assess changes in animal behavior show promise for detecting health conditions such as staggers[39] and lambing events in sheep.[40] Similarly, changes in herd association and movement patterns derived from GNSS data could indicate changes in forage utilization levels[41] or water access,[42] which can necessitate management interventions. As VF systems currently require all animals in the herd to wear a VF device, this creates tremendous potential to leverage individual animal behavior data to inform management interventions and detect behavioral changes indicating changes in health status.[43] As VF technology advances, it is likely companies will incorporate algorithms to determine health status and alerts to improve veterinary care and reproductive management.

Perhaps the greatest allure of VF is the potential economic benefit compared to traditional barbed wire or electric fences. Multistrand, barbed wire fence varies considerably in cost depending on site topography and accessibility but costs range between $10,000 and $20,000 per mile ($6,250-$12,500 per km).[44] Electrified polywire fence to subdivide a pasture can be substantially less expensive but is still costly and is estimated at $1,040 per mile ($650 per km).[45] Additionally, annual maintenance costs per mile of multistrand barbed and polywire fences are estimated at $1,324 and $352 per mile ($837.50 and $220 per km), respectively. The combined cost of installing a cattleguard base and grate is estimated at $6,500.[46]

Whether VF is an economically feasible alternative to wire or electric fence depends on the cost of materials and labor to construct and maintain a physical fence in a specific situation and the expected lifespan of the fence. These costs must be compared with the costs of specific VF systems, including the cost of animal-borne devices and potential cost of replacement batteries for these devices, the communication infrastructure, such as beacons or base stations, yearly subscriptions, and computer equipment needed to track and change boundaries. Current VF systems also require significant labor to assemble and mount devices on animals and replace failed devices or batteries as needed. Thus, economics are a key consideration when evaluating the benefits of VF technology. Economic considerations are discussed in[20] including case studies on the associated VF economics, as well as a sensitivity analysis on ranch scale factors such as stocking rates and ranch size.

Limitations and knowledge gaps

The idea of a VF system eliminating the need for physical wire and posts has certainly captured the interest of ranchers and land managers across the globe. However, it must be recognized that current VF systems include several limitations and drawbacks. Current VF systems can be costly, and the economic value of VF must be carefully compared to physical fence systems. Further, an inevitable challenge with VF systems is that animals are required to wear a VF device. Although designs will improve over time, loss or damage of VF devices will be an ongoing limitation.[13] Device failure is also an inherent reality of all electronic devices including VF systems, and failure rates higher than 50% have been observed in VF systems.[13] Other issues such as GNSS accuracy of collars may limit management, especially in small-scale pastures. A current issue with VF systems is that batteries may become depleted and fail particularly in settings where animals frequently interact with a boundary. VF devices using solar panels may help extend battery life in these scenarios. Finally, communication failure among animal-worn devices, GNSS satellites, and beacons or base stations may cause weak or incomplete virtual boundaries particularly in rough terrain or heavily vegetated areas. Just like all fences, animals will occasionally breach the fence boundary, virtual or physical, and escape the pasture or move into a restricted zone. It is expected that compliance levels will increase as more is learned about animal behavior, salient ways to designate boundaries, effective training protocols, and appropriate reinforcement schedules.

The goal of VF is for the animal to be compliant with the VF boundary and stay within the designated area and not enter any exclusion zones.[47] Once animals learn the association between the auditory and electrical cues, the animal has the ability to control its response and minimize stress.[48] Once an animal receives an auditory cue, it can continue forward movement, knowing an electrical cue will follow, or it can stop and turn back without further consequence.[49] For any technology to be adopted by livestock producers we must understand what impact it will have on animal stress and production. Within this special issue, articles assess the impact of VF on stress response, [50] heart rate,[16] and blood markers.[19] To maximize effectiveness and minimize the training window, VF needs to leverage the animals' physiology, innate behavior, and social nature.

VF studies have considered livestock species including cattle, sheep, and goats. Across these studies a variety of breeds, animal ages, and sexes have been examined. However, there is limited documentation on how these parameters impact the training process and response to VF. Verdon and Rawnsley[51] examined the effect on the training age of young cattle (6-22 months), while Kearton et al.[52] looked at the effect of a maternal demonstrator for lambs. Little is known about how differences in breed, age, and sex within species affect animal response to VF.

Moreover, for VF to be successfully implemented at landscape scales, we need to consider training not just animals but also the livestock managers. VF technology will be used by land and livestock managers with different levels of experience and technological capacities, which will necessitate different pedagogical approaches for effectively communicating with private producers, researchers, and federal land managers.[15] Lastly, although this special issue highlights the broad-scale applicability and economics of implementing VF technology, it is important for any land manager to consider what factors are most likely to contribute to successful implementation.[53]

Future opportunities

Overall, VF technology developed for livestock will facilitate adaptation to weather variability, aid in adaptive grazing, and may allow for more complete forage utilization across landscapes. However, VF is an emerging technology and is still experiencing growing pains. Factors such as cost, labor demands, battery weight and life, network coverage, device retention, and complexity of the user interface are hindering the field application of VF. As technology in general continues to evolve, so will VF. It is anticipated that batteries will become smaller and lighter, solar or motion-triggered battery recharging will become more widely available, and the communication and location detection systems will become more accurate and reliable. The user interfaces and supporting platforms will be refined and simplified making them easier for producers to track herds and adjust VF. These advances will culminate in a robust technology that could, like barbed wire more than a century ago, be a catalyst for transforming livestock production.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests. The authors certify that they have no financial interest in the subject matter discussed in the manuscript. KAE and JRB are Guest Editors for this Special Issue but were not involved in any part of the review or decision process for this manuscript.

CRediT authorship contribution statement

Hope A. de Avila: Writing – original draft, Conceptualization. **Karen L. Launchbaugh:** Writing – original draft, Funding acquisition, Conceptualization. **Krista A. Ehlert:** Writing – original draft, Funding acquisition, Conceptualization. **Jameson R. Brennan:** Writing – original draft, Funding acquisition, Conceptualization.

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Authors are from: Rangeland Center, University of Idaho (Launchbaugh and de Avila), Moscow, ID, 83844, USA; South Dakota State University, West River Research and Extension (Ehlert and Brennan), Rapid City, SD, 57703, USA