Foundations of Virtual Fencing: The Vital Role of High-Quality GIS Data

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Virtual Fencing

In Arizona and other western states, ranchers and land managers rely on thousands of miles of permanent wire fencing to manage livestock on extensive rangelands (Hayter 1939). This type of fencing has led to improved rangeland conditions in many places by aiding in the application of grazing systems. However, wire fencing can fragment landscape connectivity, pose a risk to wildlife, is a major financial investment, and provides little to no flexibility to rapidly change pasture size, manipulate grazing distribution, or avoid areas of high use or sensitive habitat within a pasture (Holechek et al. 2011; Jakes et al. 2018). As a result, there are constraints on the use of permanent fences as a tool for managing riparian health, post-fire vegetation recovery, or improving livestock distribution. Virtual fencing (VF) is an emerging precision livestock management technology used to address these limitations and increase management flexibility and adaptive capacity to respond to changing environmental conditions as part of a larger grazing management system (di Virgilio et al. 2018; Lima et al. 2018; Trotter 2010). As a management tool, VF uses invisible barriers, established by global positioning system (GPS) coordinates, that influence livestock movement with a combination of auditory and electrical cues. Primary elements include: (1) a software interface to draw virtual fence lines and the boundary zone on a digital map, which defines the allowable grazing area and exclusion zone; (2) GPS-enabled collars that are fitted around the circumference of an animals' neck and contain technology to track livestock movement and deliver auditory and electrical cues to influence livestock distribution; and (3) base stations and/or cellular towers to transmit and receive communications between the software and collars (Figure 1; for more information see Rangelands Gateway: https://rangelandsgateway.org/virtual-fence).

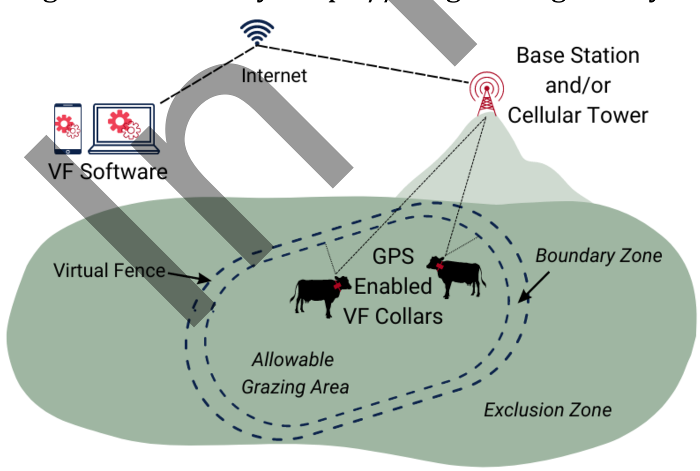

Figure 1: Conceptual model of virtual fencing (VF) hardware and software used to establish and adjust a virtual fence and the boundary zone.

Virtual fence lines are created in VF software, which requires a digital map of an entire ranch or land management area. A VF system requires high-quality, up-to-date spatial information to place the virtual fence line accurately in relation to physical infrastructure and landscape features. Ranchers and land managers may need to collect and verify geographic information systems (GIS) data associated with their area to ensure accurate mapping. GIS data is the digital representation of physical features on the Earth's surface, such as roads, pasture or allotment boundaries, location of waters, and landmarks. Without accurate GIS data, it will be difficult to use a VF system to apply precision livestock management.

Quality GIS Data Reduces Risk

High-quality, accurate GIS data is essential for all pastures or grazing allotments where VF will be used, regardless of the acreage. Acceptable accuracy in GIS data is defined as data that is the good enough to achieve your intended management outcome or reasonably collected based on your budget and available GPS device (e.g., smartphone, mapping-grade receiver, surveying-grade receiver) (Kennedy 1996). GIS data collected with a smartphone will have an accuracy of approximately 33 ft (Merry and Bettinger, 2019). Generally, this should be an acceptable level of accuracy for most purposes related to VF. Physical infrastructure such as fence lines, gates, and seasonal and permanent water features should be mapped accurately. If the mapped infrastructure is not accurate, the VF system may entrap an animal in an undesirable location, discourage an animal from moving through a grazing system, or unintentionally apply a virtual fence that would prevent livestock from accessing essential resources such as water. This can result in an animal developing strategies that breakdown the VF system's ability to successfully contain livestock within the allowable grazing area. To limit this potential risk, accurate GIS data is also recommended for other infrastructure and resources that may influence livestock movement such as: corrals, mineral and supplemental feeding stations, roads, grazing exclosures, cultural landmarks, and other landscape features. The seasonality of water features, such as dirt tanks, should be documented to ensure livestock have access to water when seasonal waters serve as the primary water source for livestock.

There are several methods to compile high-quality GIS data. Information can be gathered in the field by collecting GPS points on a smartphone application or handheld GPS unit. On public lands, it can also be obtained on publicly available GIS data clearinghouses. The Arizona Geographic Information Council is Arizona's primary source for geographic data and maintains GIS data resources for Arizona and other western states. The U.S. Forest Service maintains an online collection of GIS data, including boundaries and ownership, natural resources, roads and trails, and other datasets. The Bureau of Land Management (BLM) also has an online collection of GIS data resources for BLM administered areas. (See Rangelands Gateway to access GIS data resources: https://rangelandsgateway.org/virtual-fence). Selecting the appropriate GIS data may require technical skills to locate specific information within the geospatial data collections. In some cases, GIS file formats (e.g., files ending in .gpx, .shp, or .kml/.kmz) will need to be converted into a file format compatible with the VF software. Private lands may lack geospatial resources on GIS clearinghouses and may require collection of GPS points to create the necessary GIS data.

Data downloaded from GIS clearinghouses or obtained from agency sources should be verified to ensure accuracy. In some situations, satellite imagery (e.g., Google Earth) can be used to correct the GIS data that represent physical fence lines. However, some fence lines are not visible in satellite imagery or older imagery may not be up to date with current fence lines. It may also be necessary to verify GIS data by ground truthing or collecting real-world GIS data on a smartphone or handheld GPS unit. Ground truthing confirms the data downloaded from third party sources are accurate. If inaccuracies or missing features are found, the GIS files will need to be edited. This may require GIS software skills on programs such as ESRI's ArcGIS; Google Earth; or QGIS, a free and open-source mapping product. Some VF manufacturers may have additional resources to obtain GIS data.

Addressing GPS Error

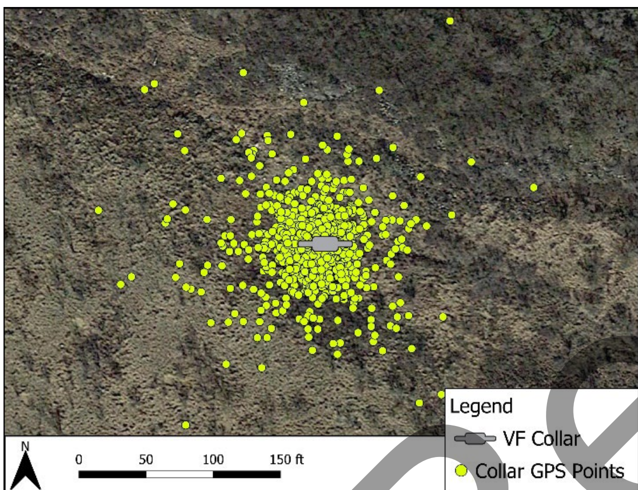

Figure 2: GPS points from a single stationary collar over a 30-day period.

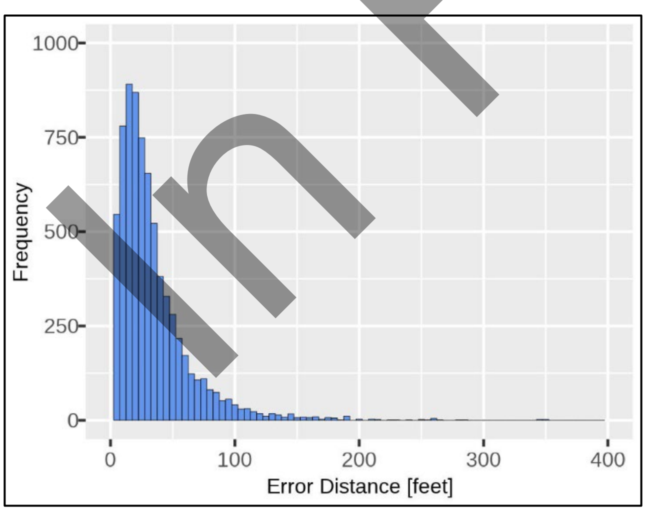

Figure 3: Distribution of GPS error from six stationary collars over 30 days. The five largest observations were removed to improve readability.

When implementing a VF system, consider GPS error. GPS works by satellites broadcasting radio signals from space, which are received by VF collars. Factors such as satellite geometry, signal blockage, atmospheric conditions, and receiver design affect the accuracy of the position determined by the GPS device (Thin et al. 2016). All GPS has some error associated with it, which can range from a few inches to thousands of feet depending on the device (Larsen et al. 1994, Villepique et al. 2008). A pilot study at the University of Arizona's Santa Rita Experimental Range in southern Arizona used six Vence CattleRider™ collars (see Disclaimer) tied to posts approximately four feet off the ground for 30 days in GPS Tracking Mode. In this mode, the collars are not in close proximity to a virtual fence and may have more GPS error than other operating modes. GPS points were collected every 30 minutes (Figure 2). The collars tested had a GPS error of 37 ft, with a standard deviation of 157 ft (Figure 3). However, the five largest observations are not shown in the figure and are very large - 409, 461, 4102, 8581, 9195 ft. These five largest observations represent 0.07% of instances but account for a large portion of the error, which would otherwise be smaller.

In some situations, the GPS error alone may place an animal within a boundary zone, when in actuality the animal is just outside the boundary zone. In this situation, the animal may unintentionally receive auditory and electrical cues. If this happens, livestock may be discouraged from moving through a grazing rotation or accessing water if the boundary zone is close to a gate or water. To limit unintended impacts of the GPS error, it is generally considered a best practice to not place a virtual fence within 100 ft of water, gates, and other essential infrastructure to give livestock ample space to safely access those areas. High-quality, accurate data combined with at least 100 ft of free space around essential infrastructure lessens the risk of animals unintentionally receiving cues. Unintentional cues can impact the system's ability to effectively contain animals within the allowable grazing area and may have consequences for animal welfare.

Conclusion

A VF system uses invisible barriers to influence livestock movement with a combination of auditory and electrical cues. The success of a VF system hinges on the relationship between the physical landscape and a digital representation of that landscape to effectively manage livestock distribution. This requires high-quality, accurate, and up-to-date GIS data. Detailed GIS data, gathered personally or downloaded from GIS clearinghouses and verified for accuracy, ensures that virtual fences are properly positioned in the VF software relative to existing infrastructure. GIS data obtained from public sources is highly likely to have inaccuracies and missing features. When this happens the GIS files must be edited. Like all GPS devices, collars will have some inherent GPS error associated with the location of each animal. Because of this, avoid placing a virtual fence within 100 ft of water, gates, and other essential infrastructure. This provides livestock ample space to safely access those resources, while minimizing the risk of livestock unintentionally receiving auditory or electrical cues.

With high-quality GIS data, virtual fences can be accurately placed to protect sensitive habitat and ensure animal welfare. Further, accurate GIS data provides a more comprehensive understanding of the terrain and physical infrastructure across the landscape, which enables improved precision livestock management and real-time tracking of livestock. Virtual fences can be easily adjusted to achieve management goals including encouraging livestock to move through a rotation, limiting access to ecologically sensitive areas, improving grazing distribution within a pasture, avoiding noxious species, and enabling targeted grazing strategies that reduce fuel loads or control invasive species (Figure 4). Ultimately, the reliability and success of a VF system depends on a foundation of high-quality, accurate GIS data to implement precision livestock management.

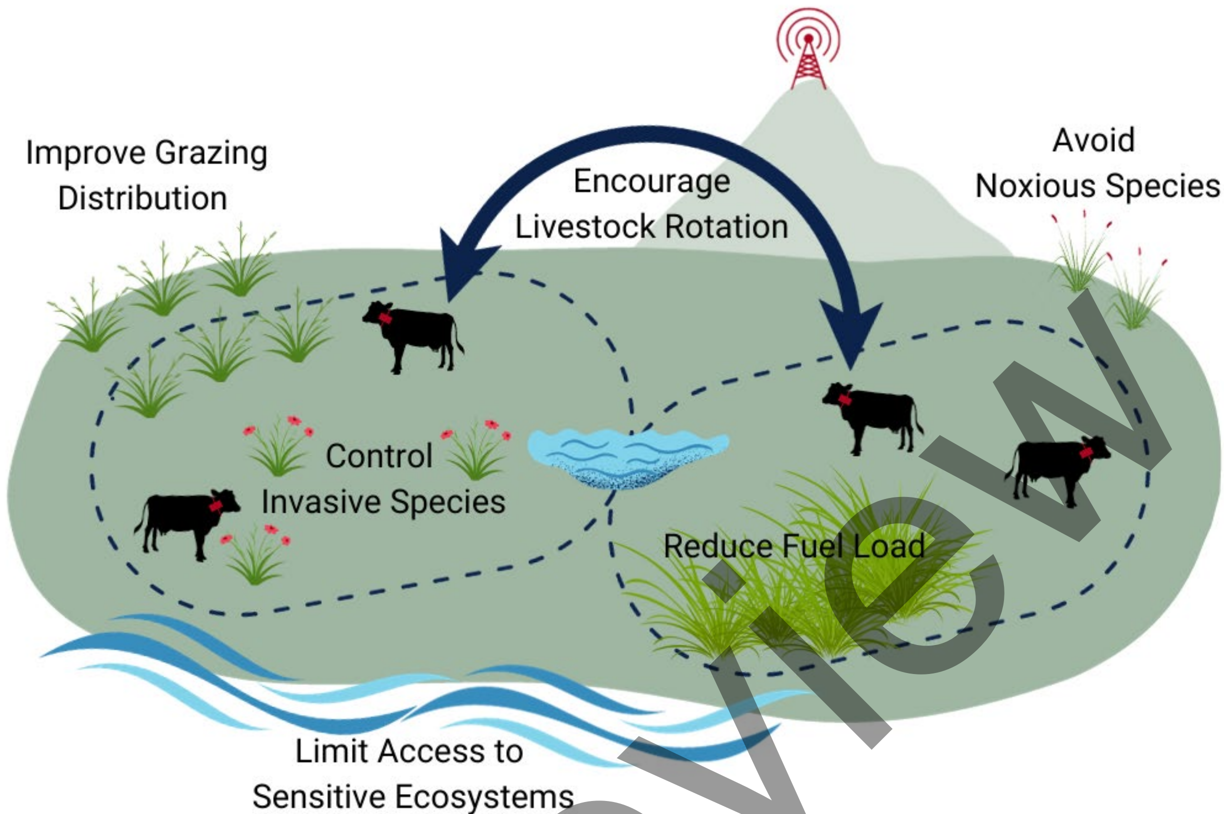

Figure 4: Conceptual model of the applications of VF.

Disclaimer

There are several companies that manufacture hardware and software for commercial use including Corral Technologies™, eShepherd™, NoFence™, and Vence™. Virtual fencing components from different manufacturers are generally not interoperable or interchangeable. Specific components, GIS data needs, software protocol, software training, frequency and duration of the cues, GPS error, livestock collaring, and livestock training protocols may vary depending on the manufacturer. Follow the manufacturer's recommendations and guidelines. The University of Arizona does not endorse a specific product.

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For additional information about virtual fencing, visit:
https://rangelandsgateway.org/virtual-fence

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