Objectives and Aims

Advancement of precision land management technologies enables producers to manage the landscape with grazing animals to strategically improve ecosystem health and sustainability. Among the more novel of these technologies is virtual fencing (VF) – borders without physical barriers – to implement precision grazing management (Anderson 2007; Umstatter 2011). VF systems operate via GPS-enabled collars on each animal. There is a three-way interaction between the collars, a base station in the field, and a user interface (software) on a computer that allows users to 'draw' their pasture boundaries. These boundaries transmit to the base station (operated by cellular and solar), which 'pushes' the virtual fence instructions to the collars. Livestock are controlled within the virtual pasture with an auditory stimulus followed by an electrical pulse if the animal goes farther into the virtual boundary. The system is designed such that animals learn the association between the auditory cures and the electrical pulse and respond to the auditory cues alone.

Grazing systems implemented with VF can help livestock producers manage the timing, duration, and distribution of grazing animals to improve natural resource management and animal performance while reducing labor and material costs by converting manual labor to cognitive labor (Anderson et al. 2014). Potential applications of VF include improved management on leased ground, crop-livestock integration, fire-fuel load reductions, riparian restoration, targeted grazing of invasive species, and wildlife habitat improvement (Boyd et al. 2014; Campbell et al. 2019; Boyd et al. 2022). As time advances, the costs of VF technology will likely decrease and lead to widespread adoption by land managers, livestock producers, and researchers. The few options that are commercially available to producers include NoFence^{TM}, eShepherd^{TM}, and Vence^{TM}, of which Vence^{TM} is the most readily available within the U.S.

Beginning in 2020, a VF working group was established to foster collaboration among researchers utilizing VF technology. Currently the working group consists of 35 individuals across 13 entities, including university, livestock producers, NGOs, and government agencies. Preliminary efforts of the working group have focused on trainings to learn and implement virtual fencing using the Vence^{TM} system. Specific needs that have been identified by the group are methods to handle, process, and analyze the large amounts of GPS data generated by the system. For instance, a herd of 130 animals with GPS fix intervals of 5 minutes may generate over 37,000 points per day. Efforts by the group have resulted in disparate data processing tools that utilize ArcGIS, R, Python, and Excel, resulting in a variety of data processing and management methodologies, duplication of efforts between groups, and a lack of standardization. Our **long-term goal** is to *develop methodologies and documentation to successfully implement VF systems and extract meaningful insights from data generated by these systems.* Efforts from this project will be shared with new users, research institutions, and other stakeholders to reduce data processing and implementation start-up time, thereby increasing the long-term impact of improved grazing management with this technology.

The **objectives** of this **enabling** proposal are to organize a **conference** for the VF working group to:

1) Standardize data acquisition, storage, parsing, processing, and analysis of VF data
2) Standardize and document terminology associated with VF systems
3) Create tutorials for successful implementation of VF systems

Objective 1: Data Management

The focus of this objective will be to develop a series of Jupyter Notebook tutorials and R markdown files to enable users not familiar with programming to access, download, and process VF data strings into usable datasets for analysis. In addition, video tutorials will be created to help users use the code with example datasets. The VF collars transmit data packets to the base station using a low frequency radio (LoRa) signal. Data packets are uploaded to Amazon Web Services (AWS) cloud storage via the base station. Working in collaboration with the Vence™ team, collaborators at the University of Arizona have developed a Python API to query, download, and parse VF data generated by their institution from AWS. One limitation of the API is it currently requires users to be familiar with Python programming to implement. Additional steps needed include automating data processing tasks that are universal across studies into the data pipeline. These include metrics common to GPS analysis such as distance, duration, and rate of travel between successive points, cleaning bad GPS points, and identifying points within virtual management zones. The data pipeline will be further automated to download, process, and store data daily. Tutorials will be demonstrated at the VF working group conference. All code, notebook, and markdown files will be made available through a public GitHub page.

Objective 2: Terminology

It is essential to define terms used with VF systems to reduce ambiguity surrounding communication of the technology for publications and presentations – for both researchers and producers. For instance, the word 'virtual' has been described in different contexts with little agreed upon definition (Anderson 2001; Palmer et al. 2004). In addition, terms such as sound and electrical stimuli, animal 'training' or 'conditioning', animal welfare, and animal 'compliance' or 'cooperation' with the system are not well documented or completely understood for this technology. For this objective, we will develop a working sub-group to identify and define terminology surrounding VF systems. Terms will be presented at the VF working group conference to further refine definitions and acceptability. VF terms will be submitted as a publication in a peer-reviewed journal.

Objective 3: Implementation

Much of the VF research has been focused on the ability to contain animals within defined management zones. Very little is known on successful implementation, costs of installing and operating VF systems, and costs and benefits of big data management from these systems. It is critical that best practices are shared among users to achieve successful implementation of VF technology. Best practices are needed for: placing collars on animals, training animals to learn the system, the scale at which the VF system is most effective, differences between classes of animals, designing effective virtual fence paddocks and rotations, and understanding the economic implications of this technology and the data generated from it. We will create a discussion board for the VF working group to share challenges and success on VF implementation. The discussion board will be synthesized into a working document at the VF working group conference to define best practices for successful implementation of VF technology. Best practices will also be presented at a VF symposium organized by PI Brennan at the Society for Range Management annual meeting in 2023.

2. Furthering the aims of the AG2PI

A key component of the AG2PI is to develop community solutions to research needs and fill gaps in data management. Anderson et al. (2013) identified a critical need for standardization of livestock GPS data processing and analysis, which has not been accomplished in nearly the decade since his publication. A multi-institutional collaboration on the standardization of VF data processing and analysis will result in effective communication of results and procedures of VF technology. Collaboration is essential in data storage and analysis design to meet the needs of all stakeholders. Standardization will also result in consistent metrics across the scientific community. Though the focus of this project is to standardize VF data from the Vence^{TM} system, protocols and code developed by this group will be applicable to all researchers looking to analyze and implement livestock GPS tracking or VF data from multiple platforms or companies. Additionally, although there is great promise in the application of VF technology to manage animals on the landscape, in order for the system to be effective, all animals in a herd must be collared. This provides a unique opportunity to collect unprecedented herd-level GPS tracking data on individual animals that can be used to assess livestock grazing behavior and distribution relative to landscape features, forage resources, animal class, and animal genetics (Zengeya et al. 2013; Bailey et al. 2015; Raynor et al. 2021). Standardization of data processing and analysis can further facilitate such meta-analyses between research projects and sites in a way that is scalable and multiplicative across regions and disciplines.

Overall success of this project will be evaluated by: successful compilation of open-source code and tutorials to enable automated processing and storage of VF data (Objective 1); defining terms and disseminating them through a peer-reviewed publication (Objective 2); and sharing best practices for producers and researchers looking to implement VF systems on their operation through presentations at the Society for Range Management (Objective 3).

3. Expected outcomes & deliverables

Though the technology itself is applied specifically to animals, grazing management can influence both plant and animal systems. A key priority of the AG2PI is to mitigate environmental impacts from livestock production. VF technology has the potential to revolutionize natural resource management in grazing systems, while simultaneously improving animal efficiency and performance. We expect data, terminology, and methodology standards generated from this proposal will result in meaningful and effective technology adoption across researcher, producer, and land management groups. By automating data processing and downloads daily, our work will further enhance the ability for grazing algorithms to be developed and integrated into livestock management decisions in real time. In addition, we anticipate knowledge and data shared across entities will help address many of the ecological, social, and economic questions pertaining to new precision livestock technology adoption. We expect that efforts from this project will result in cross-disciplinary research on precision livestock technology integration within extensive livestock systems.

At this conference, we will generate open source Jupyter notebook and R markdown files to automate data processing and handling of VF data. This will reduce duplication of efforts across institutions and reduce startup time allowing a greater focus on answering research questions instead of data processing and management.

Qualifications of the project team (0.5 pages)

The group consists of members from multiple organizations with specializations in rangeland management, animal science, data science, ecology, GPS tracking, economics, system dynamics, and sociology. PI Brennan has published papers and given workshops on streamlining and automating processing of GPS and accelerometer data for studying livestock movement (Brennan et al. 2019; Brennan et al. 2021). Co-PI Menendez specializes in systems thinking and modeling for livestock systems. Co-PI Ehlert is a state rangeland management specialist and works routinely with livestock producers to implement grazing practices to improve natural resource management. Co-PI Stephenson has used GPS tracking to evaluate resource selection of grazing livestock, targeted grazing behaviors with cattle, and social associations between cow/calf pairs and cattle herdmates. Co-PI Reuter has published in precision management of grazing cattle and has implemented a VF system for 2 years. Co-PI Hoag is an economist that specializes in analyzing decision making about issues at the intersection of agriculture and the environment. Co-PI Meiman has been leading a project in Nevada studying VF on hundreds of animals grazing thousands of acres of rangeland and pastureland across multiple land ownerships (deeded, USDI Bureau of Land Management, USDA Forest Service), and routinely works with livestock producers and natural resource managers across state and federal agencies. Co-PI Beard has used GPS tracking to evaluate grazing behavior of cattle in relation to physiological status, in addition to research focused on physiological interaction within environment of cow-calf systems. Beard also has given several Extension workshops and created material focused on beef cattle management in extensive rangelands. Co-PI O'Connor has published papers on testing VF technology capabilities to manage rangelands and has experience processing large data sets. Overall, our project team is interdisciplinary, and has the skills and dedication to realize the objectives of this proposal.

Proposal timeline

	2022-2023											
	May	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
Activity												
Monthly Group Meetings	x	x	x	x	x	x	x	x	x	x	x	x
API Creation		x	x									
Data Parsing and Processing				x								
Data Storage					x							
Jupyter Notebook/R Markdown creation						x	x	x				
GitHub page creation										x	x	x
Terminology Group Creation					x	x						
Working Group Conference									x			
Feedback from VF group members									x	x	x	
Terminology paper preparation											x	x
Present at Annual SRM Conference										x		

Engaging AG2P scientific communities & underrepresented groups

Lack of resources can make technological adoption challenging for new users. This proposal is aimed at engaging the scientific community to enhance VF adoption and data processing among researchers, land managers, and livestock producers.

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