Design of an Automatic Travelling Electric Fence System for Sustainable Grazing Management

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Abstract

Fences are used in Precision Livestock Farming (PLF) to prevent herbivores from overgrazing and under grazing forage. While effective in controlling animal entry and exit, traditional fences are not flexible enough to meet the needs of both foraging animals and plants in terms of both nutrient availability and physiological demands. An electric fencing system is a form of traditional fencing that employs an electric charge to create a barrier and dissuade animals from crossing it. Even though this system provides an effective livestock management solution; establishing, maintaining, and altering fences is a time-consuming and tough task. Currently, virtual fencing is rapidly gaining traction on numerous ranches, though its widespread adoption remains constrained by its steep costs, rendering it an impractical choice for many ranchers. Furthermore, our observations have revealed that collars, an essential to virtual fencing, come with their own set of challenges. They demand a significant amount of labor for upkeep, are susceptible to slipping off cattle, and necessitate regular maintenance. Moreover, not all animals exhibit the desired response to collar sound or shock stimuli, often choosing to disregard the virtual boundaries altogether. In this context, this study provides a novel automotive electric fencing (AEF) framework that has the capability to expand the usage of spatial grazing management and customized grazing without the need of traditional fencing. This unique AEF system consists of an autonomous mobility unit, electric fence with energizer, a GPS based navigation system and remote monitoring capabilities to improve cattle wellbeing and safeguard crops and pastures. We utilized the strain gauge load cell to measure the pressure applied to the fence by the cattle. When *cattle push the fence (pressure detected), the Arduino sends a signal to a motor controller to move the motor forward, releasing the wire. If the pressure goes off (cattle remove the pressure), the Arduino sends a signal to the motor controller to move the motor backward, retracting the wire. Additionally, if the wire is loose the sensor will tighten it and maintain a certain wire height to regulate cattle regardless of how the wire may loosen. The cattle who challenged the fencing system will get a shock that is not harmful but strong enough that they will remember it and respect the electrical fence. The cameras installed on the Unmanned Ground Vehicles (UGVs) will continuously observe various grazing management aspects and transmit the captured data to our system. This data is utilized to optimize pasture utilization, making the most of available forage resources while minimizing soil and plant ground cover degradation. Subsequently, the system will make decisions regarding relocating the UGVs to new positions. The integration of a non-harmful electric fence, remote monitoring, and the promotion of sustainable agriculture methods are among the key aspects. The system's versatility and remote management capabilities provide a cost-effective and environmentally friendly alternative for modernizing livestock management, assuring efficient grazing practices and agricultural enterprises long-term viability.*

Keywords.
Precision Livestock Farming, Grazing Management, Livestock Management, Automotive Electric Fencing, Electric Fencing Systems.

1 Introduction

The management of livestock has been a long-standing human tradition that has not changed much over the ages. Typically, cattle and other animals graze in vast pastures surrounded by barbed wire fences. Fencing is used to create boundaries to keep animals in specific locations for grazing. Several paddocks (sub-pastures) are often found on a ranch, and they are all divided by these common fences. To accomplish various ecological goals, installing fence systems requires exact management of grazing patterns. These goals include promoting biodiversity through strategic grazing management (Adler et al., 2001; Olff & Ritchie, 1998), avoiding soil erosion brought on by excessive grazing (Evans, 1997; Grieve et al., 1995), preserving natural landscapes, and reclaiming rangelands that were formerly utilized for farming (Sutherland, 2002; Van Wieren et al., 1998). The management of livestock herds must become more adaptable in response to these evolving demands. Examples include reducing animal density in areas susceptible to severe soil erosion (Gibson et al., 1987), reintroducing livestock to areas that are no longer used for agriculture (Pykälä, 2003), and making seasonal adjustments to grazing areas in compliance with designated protected zones (Gibson et al., 1987; Van Den Bos & Bakker, 1990) or grazing regulations (governmental agency) or private agreements.

However, keeping cattle and sheep in large paddocks still requires a lot of effort, particularly when considering the regular rotations needed for pasture management. Precision livestock farming (PLF) technology has proven to be quite effective in analyzing and perhaps resolving these issues. Regardless of the size of the herd, the farmer can evaluate farming methods and keep monitoring the animals' daily activities via their computer (Norton et al., 2019; Menedez III et al., 2022; Tran et al., 2022). Therefore, PLF systems have the potential to improve pasture management, animal performance as well as enhancing animal well-being, soil health, and pasture usage. For livestock grazing, a variety of PLF technologies have been developed, such as RFID tags, boluses, collars, and noseband sensors for measuring grazing behavior (Werner et al., 2017), as well as monitoring cardiovascular and respiratory patterns for assessing welfare and health (Salzer et al., 2022). Despite their efficiency in livestock management, the establishment, maintenance, high cost, and modification are labor-intensive and challenging.

Therefore, electric fence systems are frequently utilized in perimeter security, animal management, and agriculture. The employment of an electric charge to establish a barrier and discourage people or animals from crossing it is known as an electric fencing system. It usually consists of wires that have been electrified by means of a fence charger or energizer, which periodically pulses electricity at a short but strong intensity. Morris (2009; 2017) explained how electric fencing is used in sheep farming to improve grazing management techniques, such as cell-grazing, techno-grazing (an intense grazing technique incorporating paddock subdivision), and sub paddock grazing. Poole et al. (2002) conducted a large-scale field trial to assess the effectiveness of the electric fence. The trial involved installing massive fencing that extended over hundreds of meters to prevent badgers from reaching entire fields of corn (*Zea maize*) used as fodder. The focus of this study was not just protecting corn crops but also evaluating how well the fence kept badgers away from a vulnerable food supply.

Although electric fencing systems provide an efficient livestock management solution, currently there are no reliable automated fencing systems for livestock and pasture management. Consequently, a significant amount of this field's study relies on manually built fencing systems. However, there is a growing interest in developing automated electric fencing systems due to their versatility, adaptability, and safety features. These systems are essential for providing affordable fencing solutions, effective management of pasture and livestock, security, and wildlife conservation. As a result, the study presents a novel design for an automotive electric fencing (AEF) system that increases the potential for customized grazing and spatial management without using conventional fencing. This special AEF system combines GPS-based navigation, an electric fence with an energizer, a fully autonomous mobility system, and remote tracking capabilities. These elements are designed to protect grasslands and crops while improving the welfare of livestock. With a focus on sustainable agricultural methods, the device uses an electric fence that is not harmful and allows for remote monitoring. The adaptability and remote management features of the system present a cost-effective and eco-friendly way to update livestock management, help implement a combination of different grazing management practices and support the long-term viability of agricultural businesses. The remaining portions of this study are organized as follows: Section 2 represents the overview of system components, design and development of the proposed system, and methodologies for performance evaluation. Section 3 includes the results and discussion and in Section 4, we conclude the paper.

2 Materials and Methods

This proposed AEF system consists of several components, including electrical fence wire, energizer, Arduino Uno, posting system, motor controller, strain gauge load cell with HX711 amplifier and Unmanned Ground Vehicles (UGVs). In this study, we are primarily focusing on the mechanical aspects including load cell calibration, certain system components design using 3D printing technology, and ensuring the autonomous system operation in releasing and retracting the fencing wire. In the following subsection, we will provide an overview of system components, description of our proposed framework, design procedure, and performance evaluation metrics.

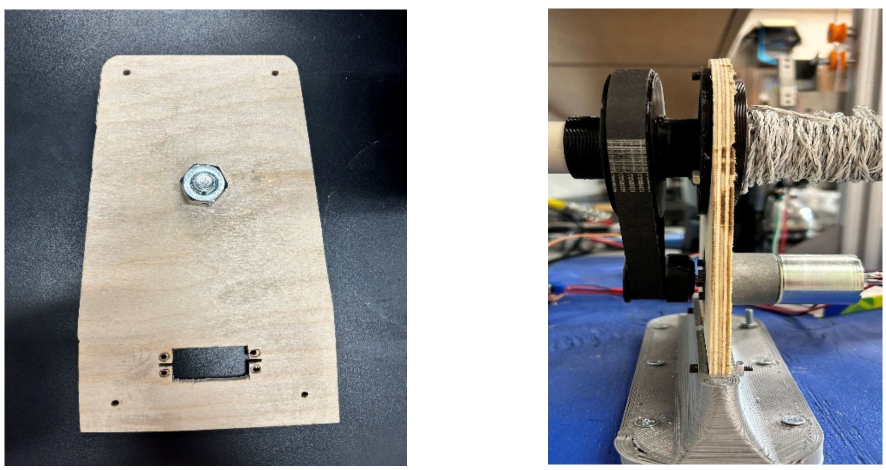
2.1 Overview of System Components

In this study, we designed and fabricated certain components including a wire retracting and releasing frame base, clutch, and fencing post mounting bracket using the 3D printing technology. Fig 1 represents the 3D printed system components. We also designed the board frame for setting the motor and clutch with the timing belt for the wire releasing and retracting system installation.

(a) Frame base (b) Clutch with timing belt (c) Post mounting bracket

Fig 1. 3D printed system components.

Fig 2 represents the designed board, and wire releasing and retracting system. In this study, we utilized polyline wire as fencing wire and aluminum bar as fencing post. Additionally, we utilized L298N dual H-bridge motor controller for controlling the direction and speed of the DC motor. We utilized a strain gauge load cell for measuring the pressure applied to the fence by the cattle. The Arduino UNO serves as the central component of our proposed system. It receives signals from the load cell via the HX711 amplifier (amplifies and converts the analogue signals from the load cell into digital signals), controls the motor controller based on the measured pressure, and executes the logic for moving the motor forward or backward.



(a) Board frame (b) Board frame with components

Fig 2. Board frame with and without installed system components.

2.2 Design and Development of Proposed Framework

We separated the process of designing the fencing system into two different sections. Firstly, the load cell was calibrated by employing the calibration factors that we determined based on the load cell's reading. Moreover, we test the system by connecting the devices according to the connections presented in Tables 1 and 2. The pseudo code for calibrating the load cell is given below:

Pseudo code for load cell calibration

// We installed the library by Bogdan Necula (Go to "**Sketch** > **Include Library** > **Manage Libraries**" and then search for "**HX711 Arduino Library**") and uploaded the code to the Arduino board.

```
function calibrateLoadCell():
    Step 1: Setup → setupLoadCell()
    Step 2: Apply known loads → knownLoads = 181g [weight of my cellphone]
                                → measuredOutputs = []
for each load in knownLoads:
     applyLoad(load)
     output = measureOutput()
     measuredOutputs.append(output)
    Step 3: Fit calibration → calibration = fitCalibration(knownLoads, measuredOutputs)
    Step 4: Calibration parameters → calibrationParams =
                                        determineCalibrationParameters(calibration)
    Step 5: Calibration Verification → verifyCalibration(calibration)
function setupLoadCell():
   → Code of initializing load cell connection and setup
function applyLoad(load):
   → Code for applying a known load to the load cell
function measureOutput():
   → Code of measuring the electrical output of the load cell
function fitCalibration(loads, outputs):
   → Code of fitting the calibration
function determineCalibrationParameters():
   → Code for determining the calibration factor [Calibration factor = Reading/Known weight]
function verifyCalibration():
   → Code for verifying the accuracy of the calibration by applying additional known loads.
```

Finally, we have installed the entire system on our own designed UGVs. Fig 3 illustrates the overall outlook of our proposed fencing system.

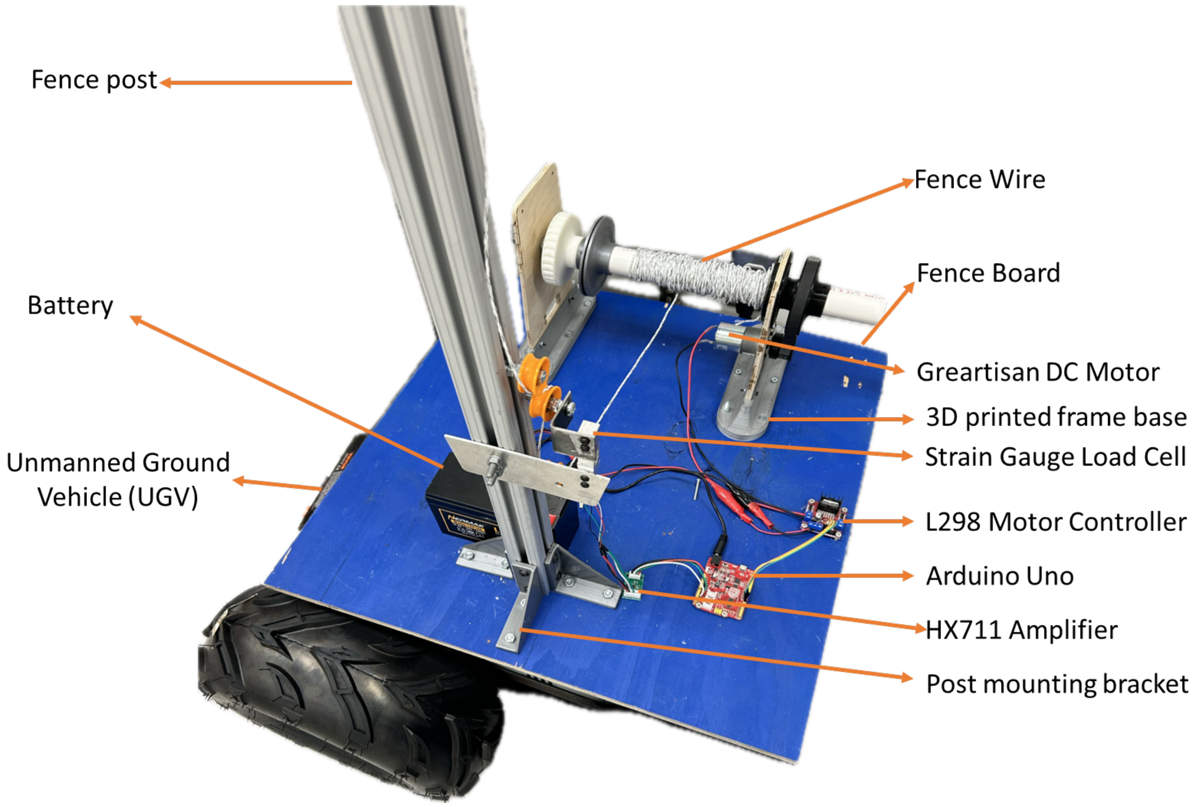


Fig 3. Overall design of AEF system.

Table 1. Pin connections of Load cell to HX711 and Hx711 to Arduino.

Load Cell	HX711		HX711	Arduino
Red (E+)	E+		GND	GND
Black (E-)	E-		DT	Pin 2
White (A-)	A-		SCK	Pin 3
Green (A+)	A+		VCC	5V

Table 2. Pin Connection of HX711 and L298N motor controller with Arduino.

Device Name	Pin	Arduino Pin
HX711 Amplifier	DOUT	A1
	SCK	A0
L298N Motor Controller	ENA	9
	IN1	8
	IN2	7

2.3 Description of the Proposed System

In this proposed system, the fence remained at an optimal heigh (~2 feet) to obstruct the path of the animal without allowing them to walk over it. However, if cattle apply any force to the fence, it will be measured by the strain gauge load cell. The load cell's analog output is amplified and transformed into a digital signal by the HX711 amplifier. Afterwards, the HX711 amplifier sends this signal to the Arduino and the Arduino detects if the livestock are challenging the fence or not based on the pressure reading. If any livestock tries to challenge the fence (pressure detected), Arduino starts transferring signal to the L298N motor controller to move the motor forward resulting in releasing the fence wire. Consequently, livestock who challenged the fencing system will get a minimum amount of shock which will not be very harsh for them, but they will remember it and keep them away from the fence. Afterwards, when the pressure goes off (pressure removed), the motor controller moves the motor backward resulting in retracting the wire. This process continues to examine the pressure and act accordingly to maintain the integrity of the AEF system.

2.4 Performance Evaluation

In this study, we will test the autonomous operation of releasing and retracting the fencing wire based on the pressure detected by the load cell for evaluating the performance of our proposed system. Table 3 represents the theoretical logic to test the system's operation.

Table 3. Logic for automatic system operations.

Logic	Action
$F_a = F_T$	Hold (neither releasing nor retracting)
$F_a > F_T$	Release
$F_a < F_T$	Retract/ Hold if it's not released

Where, $F_a$and F_T are the applied value and threshold value (calibration factor) on the load cell, respectively.

3 Result and Discussion

In this study, extensive mechanical testing was conducted to validate the functionality and reliability of the proposed system. We successfully tested the systems mechanical aspects including load cell calibration and autonomous system operation for releasing and retracting fencing wires. We calculated the calibration factor (F_T) using the following equation:

$$Calibration\ Factor, F_T = {}^{Reading}/_{Known\ Weight}$$

In this study, the value of the calibration factor was 104.484 (where known weight was 181g). Table 4 represents the simulation results of autonomous operation for releasing and retracting the fencing wire. From table 4, it can be seen that when the value of F_a is less than the F_T (initial condition), the AEF system remained idle. However, if $F_a$is greater or less than F_T, the AEF system started releasing or retracting the fencing wire, respectively.

Table 4. Releasing and retraction process of the AEF system based on load cell values.

Applied Force, $\boldsymbol{F_a}$	Threshold Value, $\boldsymbol{F_T}$	Logic	Action
23.459	104.484	$F_a < F_T$	Held
35.674		$F_a < F_T$	Held
105.695		$F_a > F_T$	Released
117.968		$F_a > F_T$	Released
103.874		$F_a < F_T$	Retracted
87.325		$F_a < F_T$	Retracted
69.763		$F_a < F_T$	Retracted
48.984		$F_a < F_T$	Held
77.863		$F_a < F_T$	Held
111.251		$F_a > F_T$	Released
115.876		$F_a > F_T$	Released
127.481		$F_a > F_T$	Released
101.467		$F_a < F_T$	Retracted
91.237		$F_a < F_T$	Retracted

In addition, the UGVs demonstrated satisfactory performance on mobility and maneuverability, allowing them to navigate varied terrains and obstacles encountered in real-world situations. We tested the performance of our UGVs by setting different terrain conditions and speed limits. The highest speed limit of our custom designed UGVs was 8 mph.

4 Conclusion

We successfully integrated the mechanical components including UGVs, load cells, 3D printed parts etc. that sets the stage for addressing the challenges for sustainable and productive livestock and pasture management in different environmental conditions. Our proposed system will provide an alternative for implementing rotational grazing, serving as a pathway to increase the species richness and ecological health in managed grassland.

Our future efforts will be directed toward improving and fine-tuning the proposed AEF system. To ensure the smooth functioning of the AEF system, we will create robust automation and control systems. Consequently, to improve the autonomy and effectiveness of the system, we will implement smart decision-making algorithms. Furthermore, YOLOv8 will be used with the IMX492 camera for object identification. We also aim to target cover crop areas in South Dakota. Furthermore, we are aiming to use temporary polywire boundaries even withing pastures with deep creeks and trees (riparian areas that sound be avoided anyway) to use large portions of the field. If the proposed AEF system is completed successfully, it will provide flexible remote management tools to assure optimal grazing practices, modernize livestock management, and aid in the long-term sustainability of agricultural enterprises.

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