BisonTrack
School of Mechatronic Systems Engineering
Simon Fraser University
250 - 13450 102 Ave
Surrey, BC V3T 0A3

August 8, 2025

Dr. Farid Golnaraghi
Professor
The School of Mechatronic Systems Engineering
Simon Fraser University

250-13450 102 Avenue,
Surrey, BC V3T 0A3

RE: MSE 411 Capstone Final Report for Bison GPS Tracking Collar

Dear Dr. Golnaraghi,

The attached document is the final report for the Wallowing-Resistant and Self-Releasing GPS Collar for Bison Herd Tracking project.

It outlines the customer, mechanical, software, and electrical requirements. As well as the team's current progress, future timeline, and budget.

The final report demonstrates how the collar was designed, how it will be manufactured, and how it will meet performance expectations in its intended environment while fulfilling the required functional specifications.

This project is sponsored by Wright Collars, based in Alberta. Wildlife biologist Rob Belanger and mechanical engineer Andrew Williams serve as company representatives, providing us with technical support. Dr. Behraad Bahreyni is our capstone supervisor.

Sincerely,

____

President, BisonTrack

Wallowing-Resistant and Self-Releasing GPS Collar for Bison Herd Tracking

Spring 2025

Final Report

August 8th, 2025

Group 4
BisonTrack

Joel Saunders | 301469793

Submitted to: Farid Golnaraghi

SCHOOL OF MECHATRONIC SYSTEMS ENGINEERING

SIMON FRASER UNIVERSITY

Executive Summary

This document outlines the current state of development for a GPS collar intended for use on bison developed by Wright Collars. Since the general bison population is diminishing, conservation efforts for this species are rapidly increasing [1]. To protect bison, tracking collars have been implemented to better understand the bison in their natural habitat, however, harsh weather and extreme behavior from the bison [2] have rendered current market options unusable. Wright Collars is developing a new tracking collar to withstand the extremities involved with tracking bison and further support protection efforts.

When considering several options, a design matrix is used to analyze each component of the design to select the superior option. The designs in this document illustrate the collar's current development status and are subject to change as the prototype is further developed.

This document describes the projected timeline, budget allocated to create a working prototype, and describes the subsystems in place for the project. Mechanical systems consist of a housing for a drop-off design; this component compared a seat belt and pin design with a design matrix, and a decision was made to continue development of the seat belt design. A history of seat belt design versions is included, which comments on improvements made, and the manufacturing of mechanical parts is addressed. The electrical portion compares different microcontrollers, satellite communication networks, GPS, and DC-DC converters with design matrices to select the optimal design. Energy consumption is addressed, lowering the minimal batteries for 4 years of operation to 2. Furthermore, software specifications are defined for subsystems necessary to create a working prototype.

Table of Contents

List of Figures

List of Tables

Glossary

Acronym	Description
UART	Universal Asynchronous Receive Transmit
DC-DC	Direct Current - Direct Current (Power Supply)
GPS	Global Positioning System
PCB	Printed Circuit Board
ADC	Analog to Digital Converter

Introduction

Overview

Bison populations once roamed North America in vast numbers, playing a crucial role in maintaining the ecological balance of grassland ecosystems [2]. These massive herbivores helped shape their environment through grazing patterns that promoted plant biodiversity and soil health. However, due to habitat destruction, overhunting, and human encroachment, their populations declined dramatically, resulting in them being classified as a "near-threatened species". Today, conservation efforts aim to restore bison populations and protect their natural habitats [2].

A critical component of these conservation efforts is the ability to monitor bull bison movement patterns, assess habitat range, and mitigate the risk of disease transmission. Knowing the location of these animals is essential for understanding migration routes, identifying seasonal behavioral changes, and detecting potential interactions with livestock that could facilitate the spread of disease. However, existing GPS tracking devices have proven inadequate for use with bison. These devices are typically designed for various smaller animals but fail to endure the rigorous and strange physical activities of bison, such as shaking, rubbing against trees, fighting amongst each other, and wallowing in dirt [1]. As a result, GPS collars often snap or break, rendering them ineffective for long-term tracking and data collection.

Currently, no collars available on the market can withstand the wear and tear of an adult bison. As a result, most collars fail to survive even two years, making long-term bison tracking impossible, and all other attempts result in unsustainably high costs.

Requirement Justification

The tracking collar must operate reliably in extreme environmental conditions for a minimum of two years, with a design goal of up to four years, while consistently providing accurate position data. Achieving this longevity will make bison monitoring more cost-effective and sustainable for conservation efforts. To reduce operational costs, the system incorporates the Kinéis satellite network and its corresponding module. The drop-off mechanism is a critical component and must be both durable and dependable to minimize failure risk, ensuring the collar remains functional for its entire service life. The specifications outlined in this report define the functional and technical parameters required to meet these performance and durability objectives.

Timeline

This project follows a timeline to ensure efficient development, testing, and deployment of the Bison GPS Tracking Collar. Key milestones include design finalization, prototype fabrication, testing, integration and final implementation.

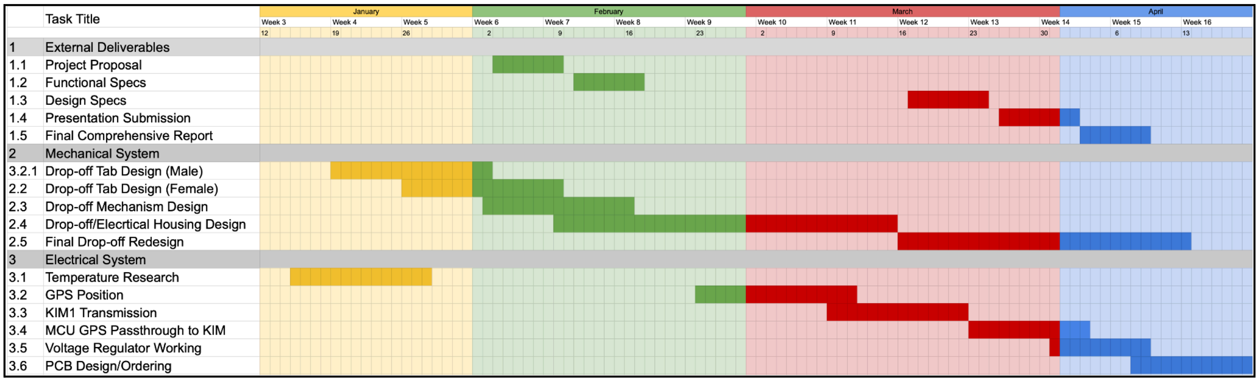

Figure 1: Term 1 Project Timeline Gantt Chart

Figure 2: Term 2 Project Timeline Gantt Chart

The project followed a structured timeline from concept to completion. During the Conceptual Design Phase (Months 1-2), we conducted research, created initial designs for both the seatbelt and pin-style drop-off mechanisms, ran preliminary simulations, and researched essential electronic components. In the Prototype Development Phase (Months 2-6), we iterated on the seatbelt designs several times, developed the motor actuation system, troubleshooted satellite transmission issues, created the PCB design, and began initial hardware integration. The Testing Phase (Months 6-7) focused on performance evaluation and confirmation of design validity, and ensuring the reliable operation of the microcontroller circuit. Finally, in the Final Adjustments and Delivery Phase (Months 7-8), we refined the designs, completed the data collection software, measured power data, strength tested the drop-off mechanism, and prepared the system for presentation, successfully meeting all project objectives.

Budget

Wright Collars has allocated an initial budget of $2,500 CAD to our capstone team. Planned expenses include electronic components, prototyping materials (such as 3D-printing filament and epoxy), and field-testing equipment. The electrical and mechanical subteams will have been allocated $1,000, with the remaining $500 reserved for unforeseen expenses. By the end of the project, we had spent $963.39 on electrical and $667.39 on mechanical, coming out to $1,630.78 total, falling well below our allocated budget, leaving the contingency fund untouched.

Our purchases are detailed in the table below, outlining the selected components for this capstone project:

Table 1: Electrical Budget

Name	Price (CAD)	Status
LPC802 Development Board (Microcontroller)	$51.72	Purchased
SAM-M10Q Development Board (GPS)	$51.68	Purchased
KIM1 Evaluation Board (Satellite Communication Module)	$389.00	Purchased
Miuzei MS24 (20kg Servo)	$21.99	Purchased
TPS63021DSJT (Buck Boost Converter)	$20	Purchased
PCB (from PCBway)	$50	Purchased
SAM-M10Q	$51	Purchased
KIM2	N/A	Shipped by Wright Collars
LPC802	$5	Purchased
J-link	$92	Purchased
Ribbon Cables	$25	Purchased
Accessory Components	$51	Purchased
Soldering Heat Gun	$120	Purchased
Solder	$6	Purchased
Solder Remover	$6	Purchased
Solder Paste	$13	Purchased

Total:	$963.39

Table 2: Mechanical Budget

Name	Price (CAD)	Quantity	Status
Top Plate	$35.41	2	Purchased
Main Body	$41.06	2	Purchased
Bottom Plate	$11.49	2	Purchased
Tongue	$62.93	2	Purchased
Slanted Tab	$36.44	2	Purchased
Rack Tab	$72.71	2	Purchased
Servo Motor	$24.63	2	Purchased
Pinion Gear	$19.50	2	Purchased
Fasteners	$42.27	1	Purchased
Grease	$16.78	1	Purchased
Total:	$667.39		

Mechanical

Housing Design

The tracking collar needs to withstand harsh weather conditions, dust, water, impacts from wallowing, and other aggressive behaviours exhibited by bison. Additionally, the mechanical structure must not buckle or deform too much lest it compromise the internal components. The requirements for the housing of the collar components are listed in *Table 3*.

Table 3: Drop-off Design Housing Requirements

Housing Requirement	Description
Temperature Resistance	The housing must survive harsh Northern Alberta environments: temperature ranges of -40 to 40°C.
Robust	The assembly must be robust and resist the effects of a bison's wallowing, play fighting, swimming, rolling in mud, etc. To protect internal electronics and mechanisms.
Compact	The housing must be compact and minimally intrusive in the bison's day-to-day life.

Drop-off Design

Joining each end of the collar must be done with a robust solution to withstand the harsh conditions the collar will endure. The exact specifications that the drop-off must be designed for are listed in *Table 4*.

Table 4: Drop-off Design Functional Specifications

Functional Specification	Description
Tensile Load	The drop-off must be able to withstand a tensile force of 990kg.
Power Draw	The drop-off mechanism mustn't draw excessive power.
Release Constraint	The drop-off must be capable of releasing under tension.
Device Lifespan	The mechanism must remain operational after 4 years of use on a bison.
Environment Resistance	The assembly must withstand dust and water.
Temperature Resistance	The drop-off must operate in harsh Northern Alberta environments, with temperature ranges of -40 to 40°C.
Size Constraints	The main body must be designed within a 90mm by 90mm by 50mm space.

This section will detail the two mechanical structures that are being considered for this design, chosen based on their robustness, debris resistance, simplicity, size, cost, and scalability

Seatbelt Design

Similar to the seatbelt design in modern vehicles, this design takes inspiration from the idea of a keyed part being held by a locking slide and adapts it to the collar design. The key is held in place by a mechanism that uses a servo motor to move a sliding part; this part fits into a cavity in the key which secures the drop-off.

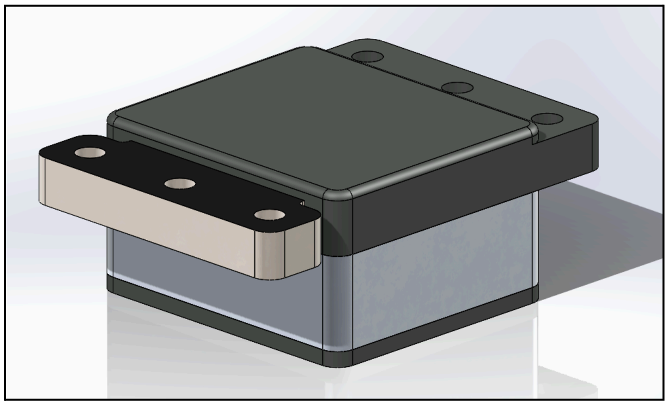

Figure 3: Seatbelt Design SolidWorks Model

Pin Design

The pin-based drop-off design was conceptualized from examining prior animal tracking collars. This design utilizes two pins, which lock into a holding piece with two steel ball bearings that fit into a cavity in each pin. The mechanism uses a spring-locking pin mechanism to push and hold the two ball bearings in place. The drop-off uses an actuator to push the locking pin, thereby allowing the ball bearings out of their cavity, allowing the pins to release.

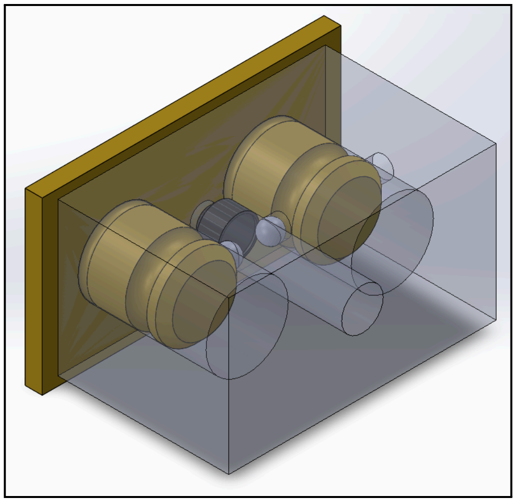
Figure 4: Pin Design SolidWorks Model

Design Matrix

Robustness describes the general strength of each design option, gauging how each design could endure rough physical conditions they may encounter in operation. This criterion exhibits a high weight as the importance of design robustness is a fundamental quality of the drop-off. A high score indicates better robustness.

Size details how big this design may be, with higher scores indicating a more compact design and lower scores describing the design as large or inefficient.

Cost details each design option's cost to produce, with low scores being more expensive and high scores being cost-effective. The weight of cost is lower, as other factors such as robustness are more important.

Scalability describes how each design can be transferred to a collar design for different animals. Given that this design is specific for bison, Wright Collars has put low importance on making a design that can scale, thus lowering its weight in the criteria. A low score represents a design that cannot be scaled up or down, while a high score indicates easy scaling.

Table 5: Drop-off Seatbelt vs Pin Selection Matrix

Criteria	Weight	Seatbelt	Pin
Robustness	5	5	2
Size	3	2	4
Cost	2	2	4
Scalability	1	1	3
	Total	36	33

Decision

The seatbelt design was chosen as the final design for the drop-off mechanism. Based on the static tests of each design, it was determined that the seatbelt design showed significant advantages in structural integrity compared to the pin design.

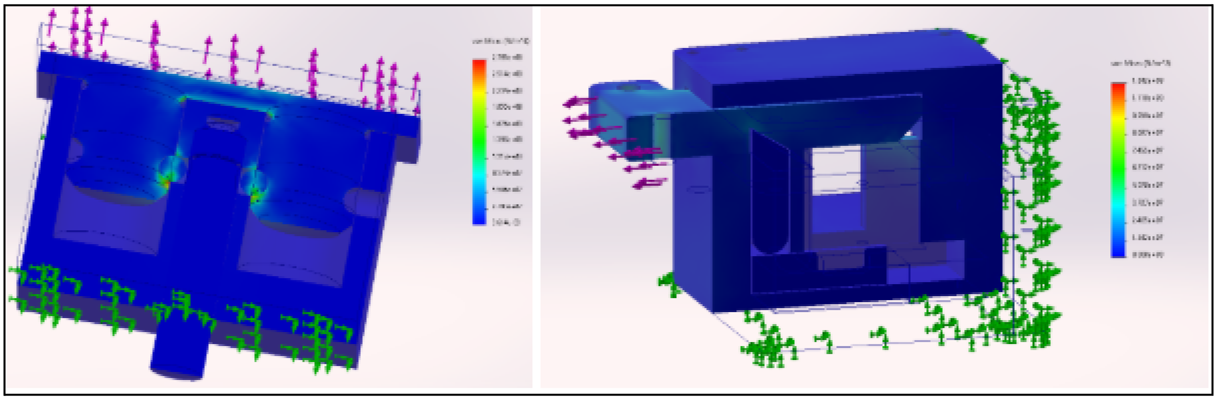

Figure 5: Drop-off Pin (Left) and Seatbelt V1 (Right) SolidWorks Simulation

Compared to the pin design, the seatbelt design demonstrated more predictable behavior under stress, which improves the overall reliability of the system. This reliability is especially important in remote or rugged environments, where failure could result in lost data or harm to the animal. Due to its strong performance in these tests, the seatbelt design earned a high robustness score and was ultimately selected as the most suitable option.

Along with the decision to proceed with the seatbelt drop-off mechanism, an internal mechanism was favoured over an external one. Being an internal drop-off mechanism means it is housed within the battery container, which is also houses the electronics . This allows for the wiring to be streamlined and minimize this point of failure.

The mechanical subsystem of the BisonTrack GPS collar was designed to meet rigorous durability standards while enabling a reliable, servo-actuated drop-off feature. The design focused on withstanding extreme bison behavior and environmental exposure, while remaining serviceable and manufacturable.

Design Evolution

Drop-off Version 1 Versus Version 2

Version 1 of the seatbelt-style drop-off was a barebones prototype that proved the concept but was too large and relied on a weak actuation method. Version 2 addressed these issues by implementing a more compact, servo-actuated release system.

It uses a rack and pinion to drive the release bar, providing torque multiplication to ensure consistent actuation. This redesign made Version 2 approximately 14mm thinner than Version 1. Another issue with Version 1 was its vulnerability to dust and debris, as the tongue entered directly into the servo motor assembly. Version 2 shortens the tongue and fully seals the servo and rack from environmental exposure.

Version 2 of the drop-off mechanism maintained the same core functionality throughout its iterative design process; however, its external dimensions evolved over successive revisions. The final version is now 6mm thinner, 10mm wider, and 10mm longer than the initial iteration of Version 2. Although each revision was internally tracked using distinct version numbers, the changes between iterations were not substantial enough to warrant classification as separate versions. As such, the finalized design will continue to be referred to as Version 2.

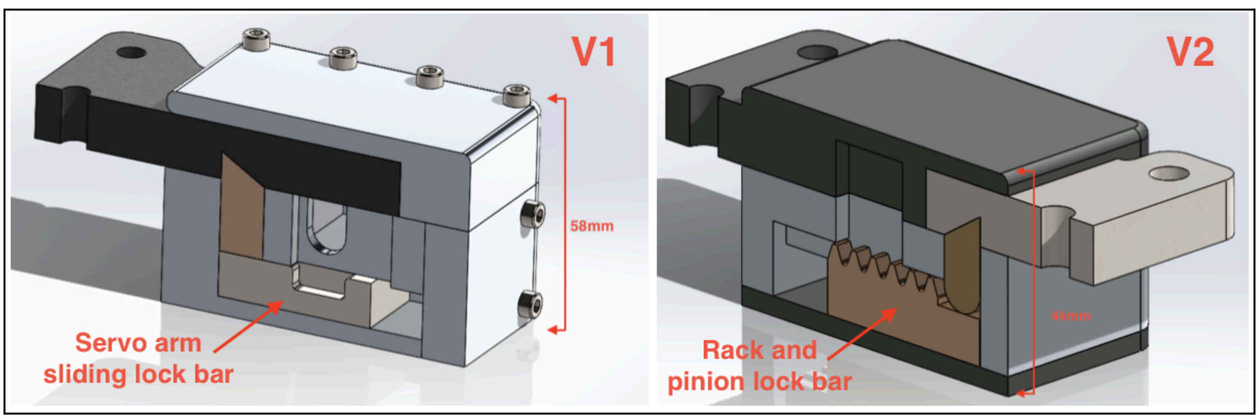

Figure 6: Drop-off Version 1 vs Version 2 SolidWorks Models

Table 6: Seatbelt V1 vs V2 Selection Matrix

Criteria	Weight	Seatbelt V1	Seatbelt V2
Tensile Strength	5	5	5
Size	4	2	3
Debris Resistance	3	1	4
	Total	36	49

Table 7: Drop-off Seatbelt Actuation Selection Matrix

Criteria	Weight	Servo Arm	Rack and Pinion
Robustness	5	5	5
Release Reliability	5	2	4
Simplicity	2	2	3
Cost	2	4	1
	Total	47	53

Locking System Improvements

Stress testing of early prototypes revealed critical mechanical weaknesses that informed the next round of design refinements. The original pinion gear, printed in plastic, failed during motorized actuation due to narrow gear teeth. A new rack was designed to interface with an off-the-shelf Mod 8 brass pinion gear, ensuring proper meshing and actuation force. In parallel, failure was observed during load tests on the triangle locking tab where the base of the tilted face aligns with the main housing. Applying 10000-N tensile forces to the male locking tongue, finite element simulations revealed high stress concentrations at this point; replacing the flat interface on the slanted locking tab with a curved surface reduced stress concentrations from 1.388e+08-N/m^2 to 1.16+08-N/m^2, a 16.43% reduction, increasing the durability of the locking system. Despite the benefits of the curved locking tab, our team determined that the reduced stress concentrations were not feasible given the added machining complexity and issues with non-linear release forces, which could compromise the ability for the drop-off to guarantee collar disengagement, a flat interface was kept on the slanted locking tab.

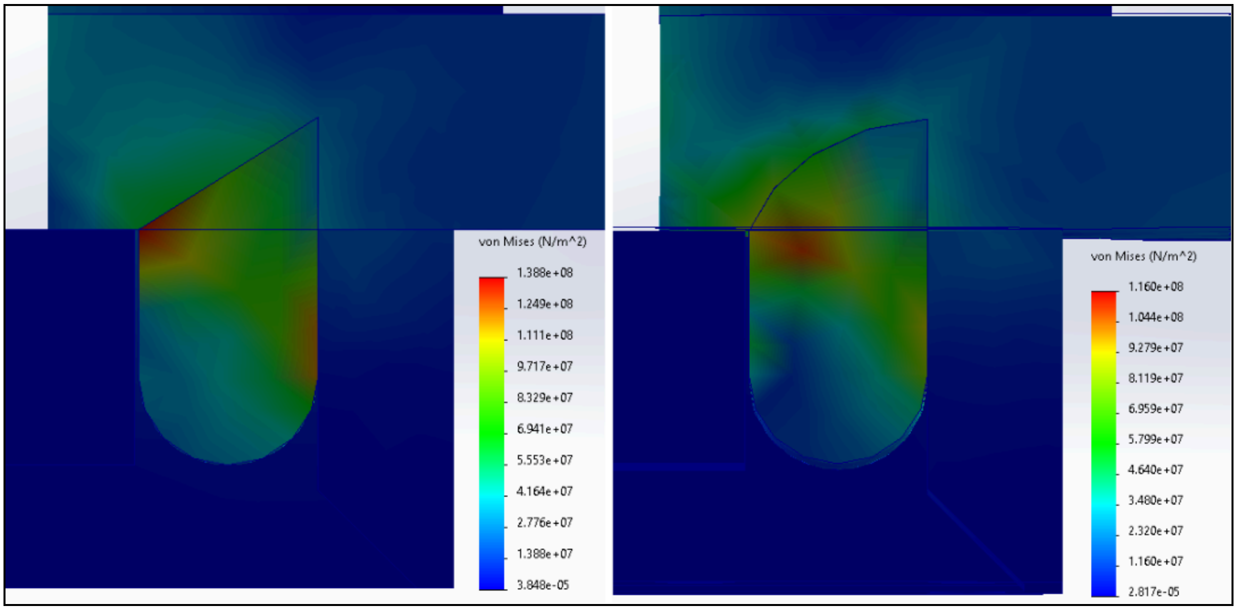

Figure 7: Slanted Tab (Left) Versus Curved Tab (Right) 10000-N Tensile Test Results

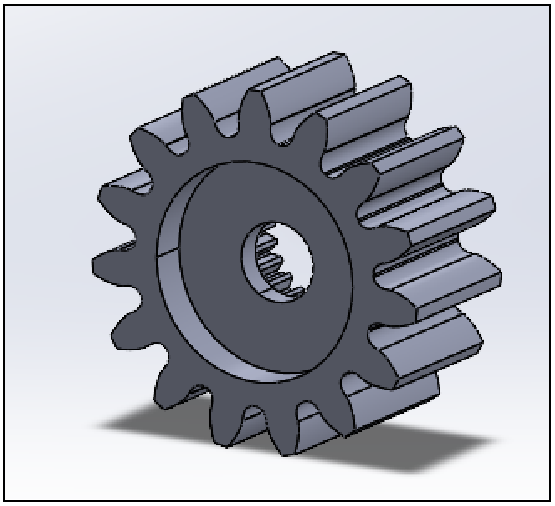

Figure 8: Selected Module 0.8 Pinion Gear

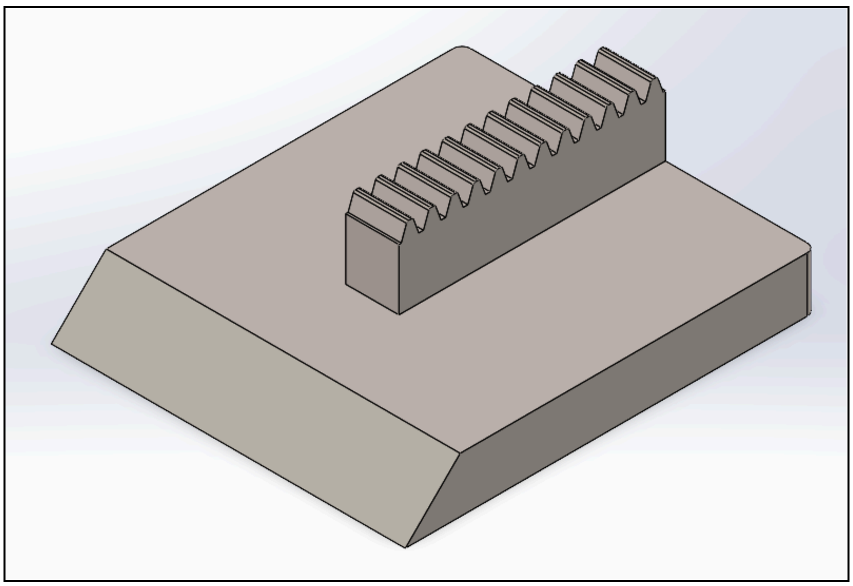

Figure 9: Redesigned Rack Slider for New Pinion Gear

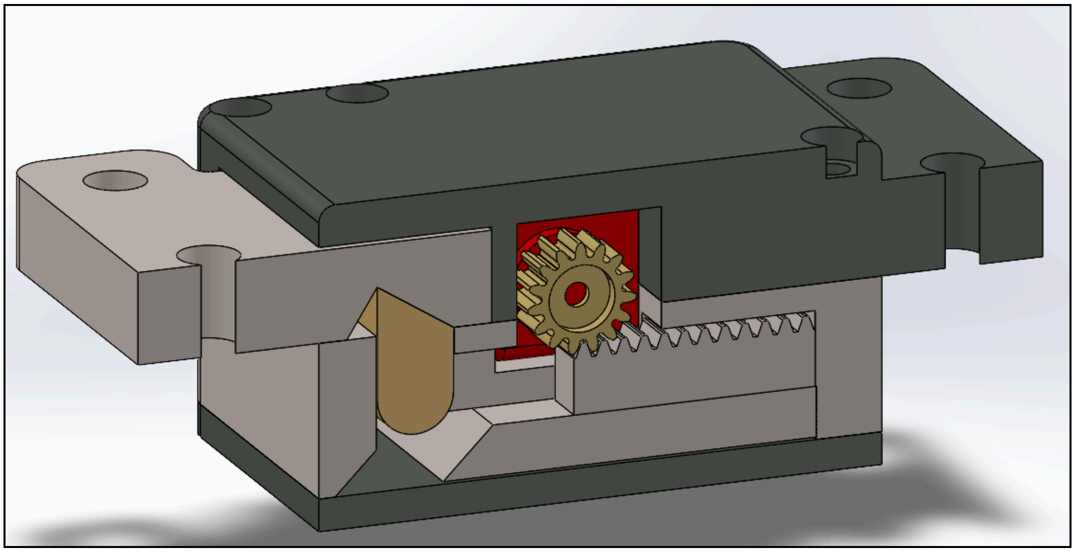

Figure 10: Final Version of Drop-off with New Rack and Pinion Design Integrated in Drop-off

Manufacturing Process of Mechanical Parts

Early Prototyping

Initial development focused on the seatbelt-style drop-off mechanism, selected for its potential to provide a secure yet releasable connection under load. 3D-printed prototypes were used to validate key design assumptions, including component fit, actuation reliability, and overall mechanical durability. These early prototypes allowed for rapid iteration, revealing issues such as misaligned geometry, structural weak points, and challenges related to assembly and motion. Insights gained from this process guided refinements that improved the drop-off's functionality and manufacturability.

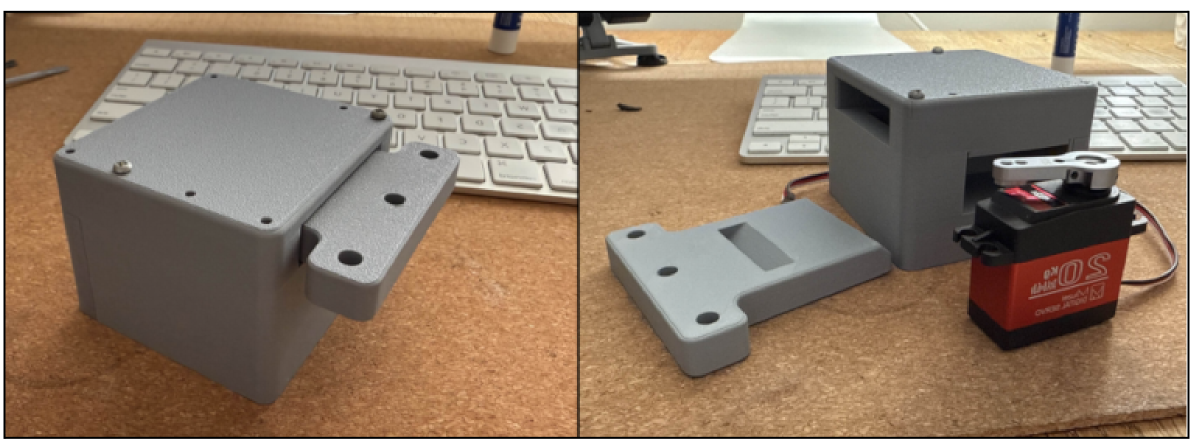

Figure 11: Initial 3D-Printed Drop-off Mechanism

Machining and Materials

To meet durability requirements, the drop-off top plate, bottom plate, and main body were CNC machined from 6061 aluminum, and the locking tab, rack tab, and locking tongue were CNC machined from 304 stainless steel. JLCCNC was contracted to manufacture the main mechanical assemblies, which were delivered with excellent tolerances that closely matched CAD specifications. Complications with the male locking tongue arose during machining, as a 45-degree cut could not be made given the geometry of the part. This was resolved by extending the cut to allow a 90-degree cut to be made, which would retain the geometry required for the design to securely lock reliably. Additionally, one issue not apparent in plastic prototypes emerged in the metal version: axial binding of the slanted locking tab during off-axis pulling. This was resolved through physical testing and consultation with machining experts.

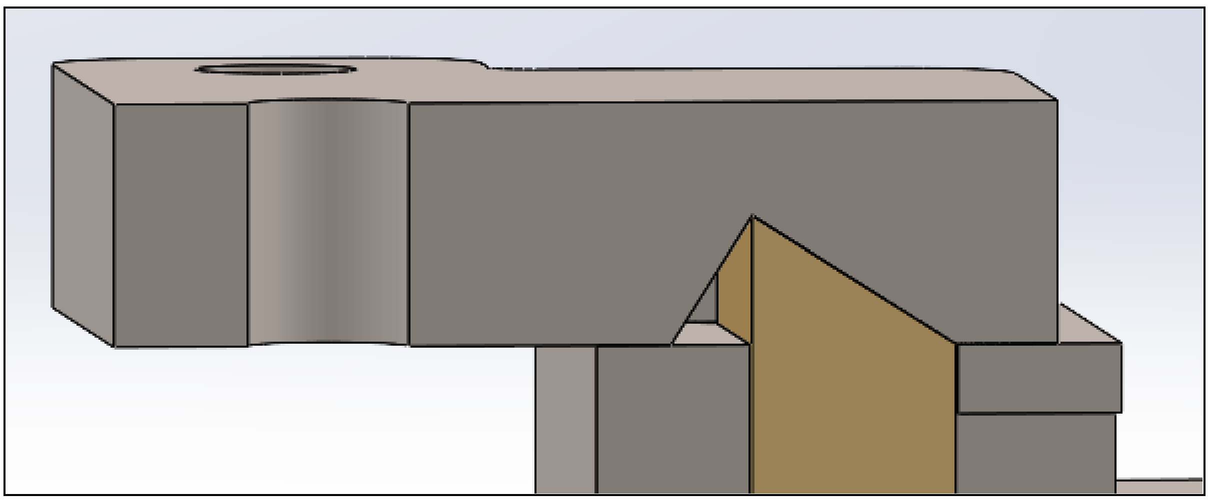

Figure 12: Locking Tongue Cutout for Simplified Machining

Integration and Refinement

Further refinements were made to the internal geometry of the drop-off housing to improve wire routing and seal integrity. A waterproof and cold-temperature resistant heavy-duty grease was selected to protect internal components from dust and moisture intrusion as well as mitigate the risk of galvanic welding. To support demonstration efforts, a mock battery box and cable routing assembly were constructed to simulate field-ready integration. Additionally, experimental bottom plates were machined in collaboration with SFU's on-campus machine shop to support rapid design iteration.

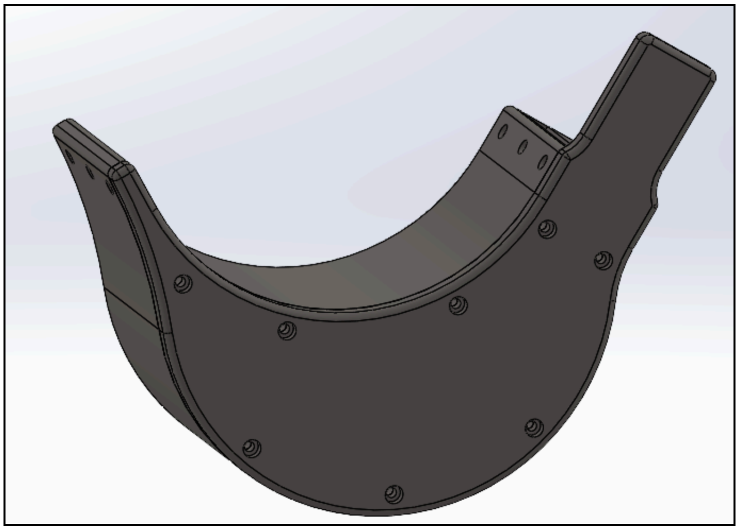

Figure 13: Drop-off Demonstration Battery Box

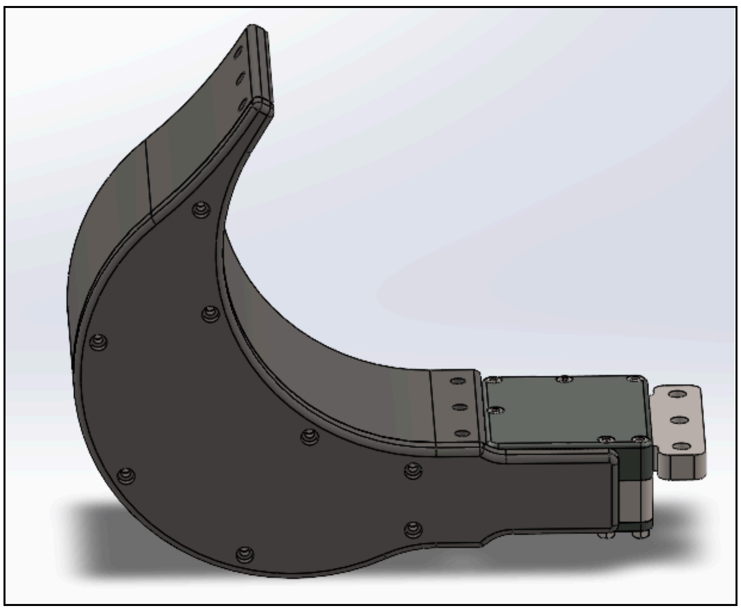

Figure 14: Drop-off Attached to Demonstration Battery Box

Testing Procedures

Release Testing

As per projected operation conditions of the drop-off design, testing the release mechanism under tension is required to identify any flaws which could compromise the system's ability to detach from a bison. An experimental test was performed with two individuals pulling each end of the drop-off, and sending it a release command. The test took a 3D-printed drop-off made out of PLA, which would better scale the results for the context of the test, as humans are not as strong as bison. Results of this test yielded enlightening and satisfactory results; the drop-off could reliably release under tension, however the male insert would grind against the drop-off housing, which indicates a potential binding issue that would prevent consistent release in a practical environment. This issue was solved on the machined version of the design by filing down burred, sharp edges and applying heavy grease, which resulted in smoother release under tension.

Loaded Hang Testing

To test the initial durability of the 3D-printed drop-off, hang tests were conducted on the plastic prototype with a 165-lb load. The drop-off was tied to a swinging apparatus, with a wooden handlebar attached to the male locking tab, and each member of BisonTrack let the design hold their weight. The design held briefly while loaded with 165lbs, however failure occurred at the top plate of the design. Given that the part was not printed with 100% infill and the machined part would be made of a stronger material, plate thickness was increased by 0.5-mm to reduce the likelihood of this failure occurring during use on a bison.

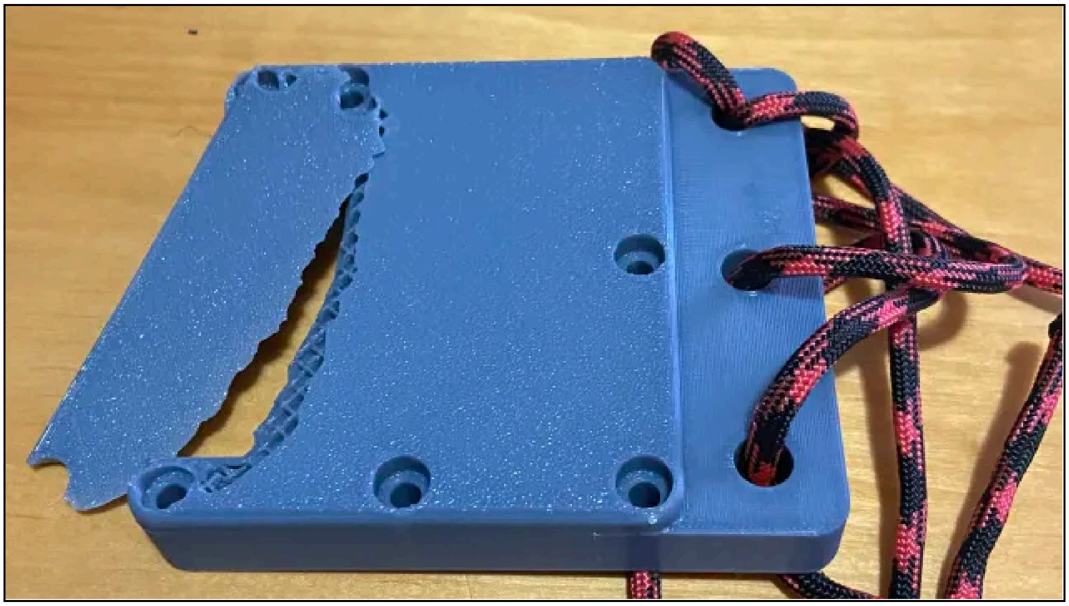

Figure 15: 3D-Printed Top Plate Hang Test Failure

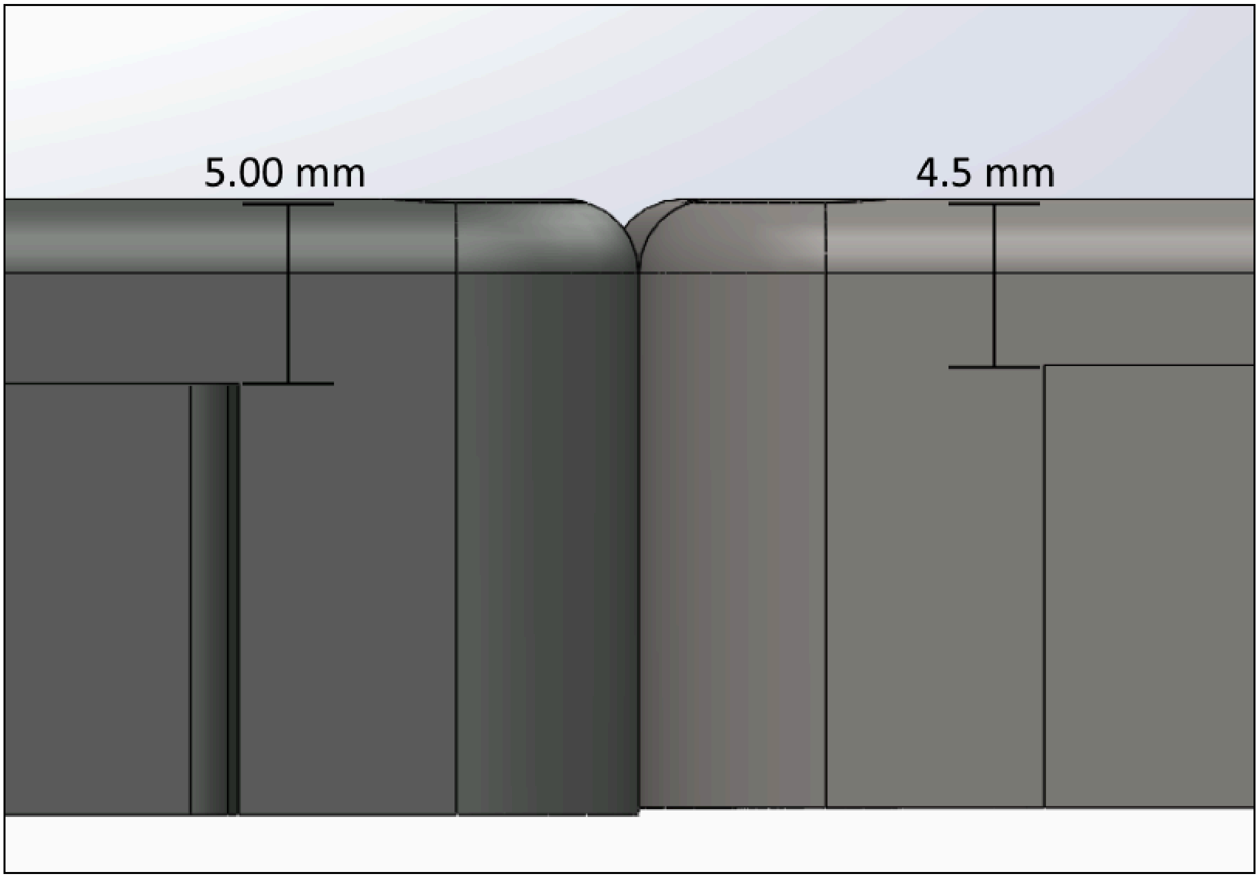

Figure 16: Top Plate Adjusted Thickness (left) Versus Pre-Testing Thickness (right)

A second hanging test was conducted using the CNC machined drop-off constructed out of aluminum and stainless steel components, using a paracord harness and a 365-lbs load. This design performed exceptionally, and released smoothly following the test, proving the current design to be up to a satisfactory standard for handling tensile loading.

Figure 17: Drop-off Tensile Stress Testing Setup

Dirt and Mud Testing

As the bison tracking collar is intended for use on bison in their natural habitat, the drop-off design must be able to withstand environmental strain. To test the design according to real-life conditions, the drop-off design tested was constructed with aluminium and stainless steel parts. This design was then buried in the dirt approximately 100mm under the surface and compacted numerous times. The drop-off unit was then sprayed with a hose to emulate muddy conditions. Once the exterior of the drop off was dry, the mechanism was easily unlatched and the tongue released with no additional resistance after enduring the mud. There was no dust or water ingress into the internals of the drop-off mechanism observed after disassembly.

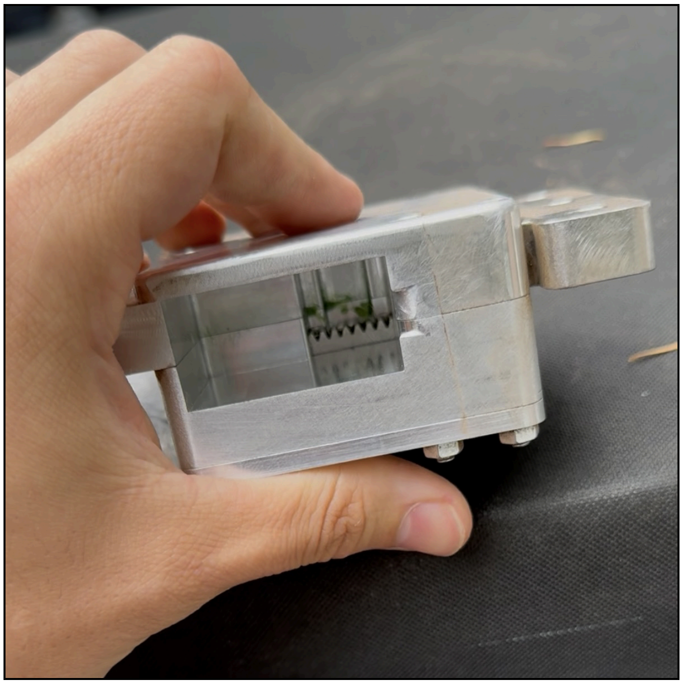

Figure 18: Drop-off Main Body After Debris Ingress Testing

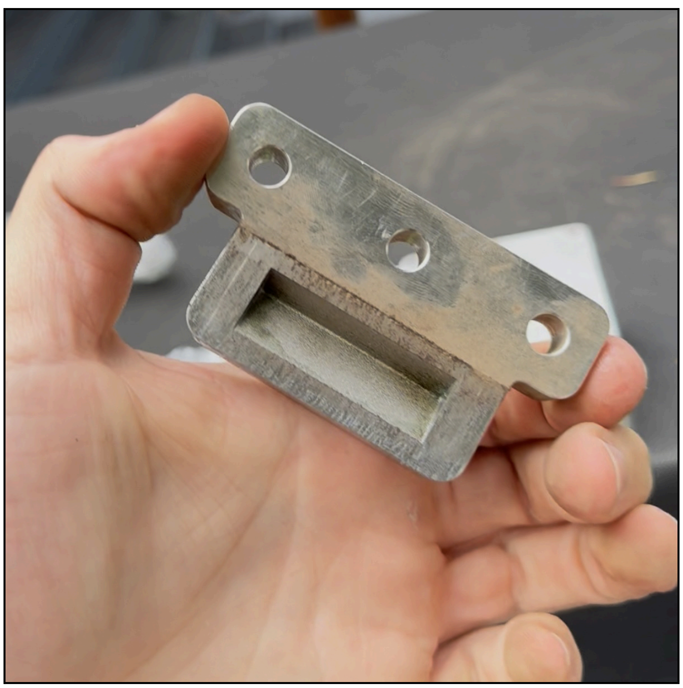

Figure 19: Drop-off Tongue After Debris Ingress Testing

As visible in *figure 18* and *figure 19*, there was no dust or water present past the tongue or into the main body, proving the design to be satisfactory against dust and water ingress.

Servo Assembly Impact Testing

With the machined model loaded with a servo motor, the assembled drop-off unit was thrown and rolled across asphalt from various heights and speeds. Despite extreme abuse of the drop off mechanism, made evident by the surface damage on the unit, both the drop-off as well as the servo motor remained entirely functional and actuated smoothly. One flaw was observed within the internal mechanism however: the selected 0.8 module gear suffered shearing of a tooth during impacts while connected to the rack. Given that the gear is made of brass, selecting a gear made from a material with improved shear strength could be done to reduce the likelihood of this failure occurring on a live collar. The gear was rotated 180-degrees to test actuation and release of the internal mechanism, which resulted in the servo motor properly actuating and the drop-off successfully releasing after the impact testing.

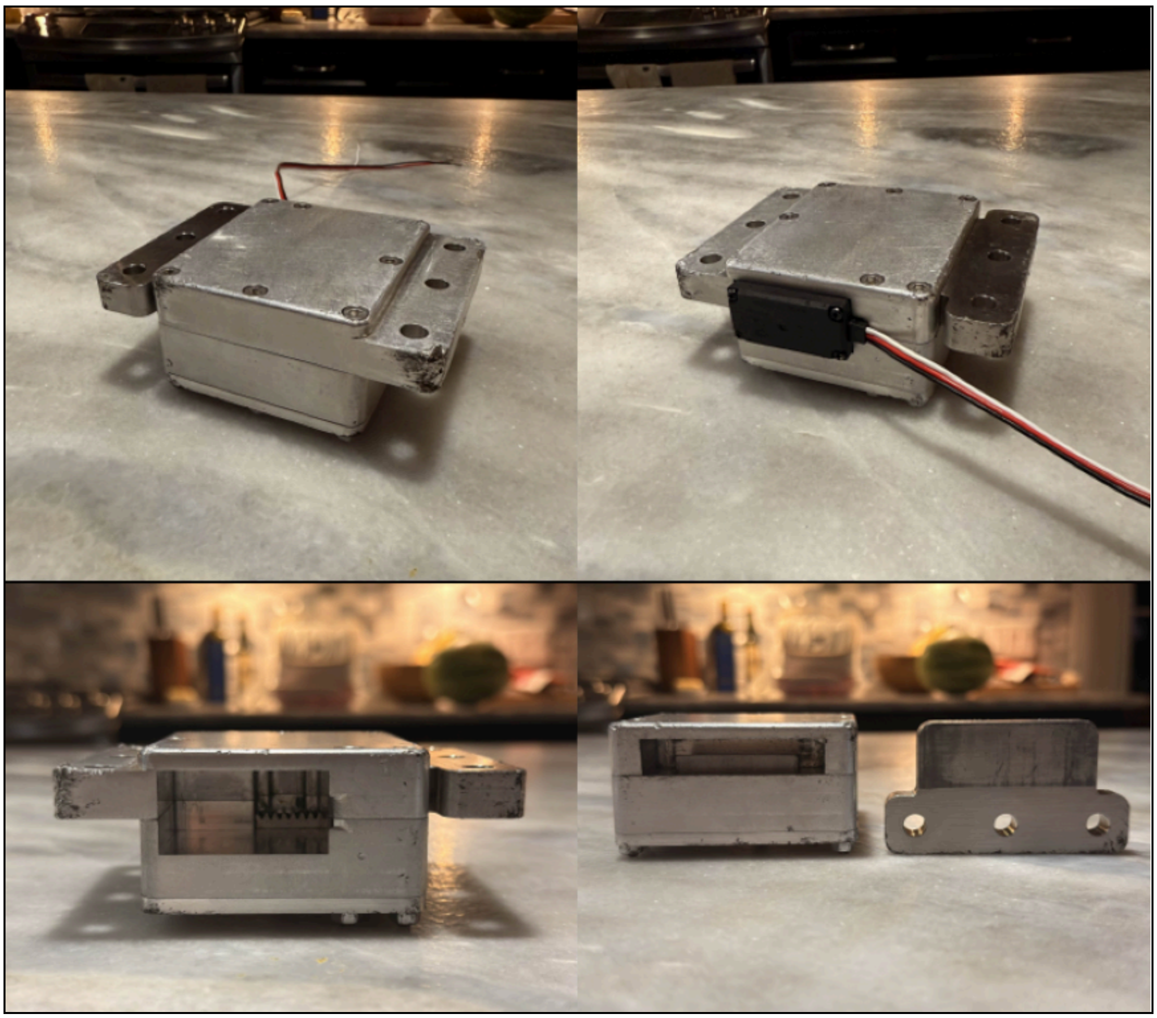

Figure 20: Drop-off External Condition After Impact Testing

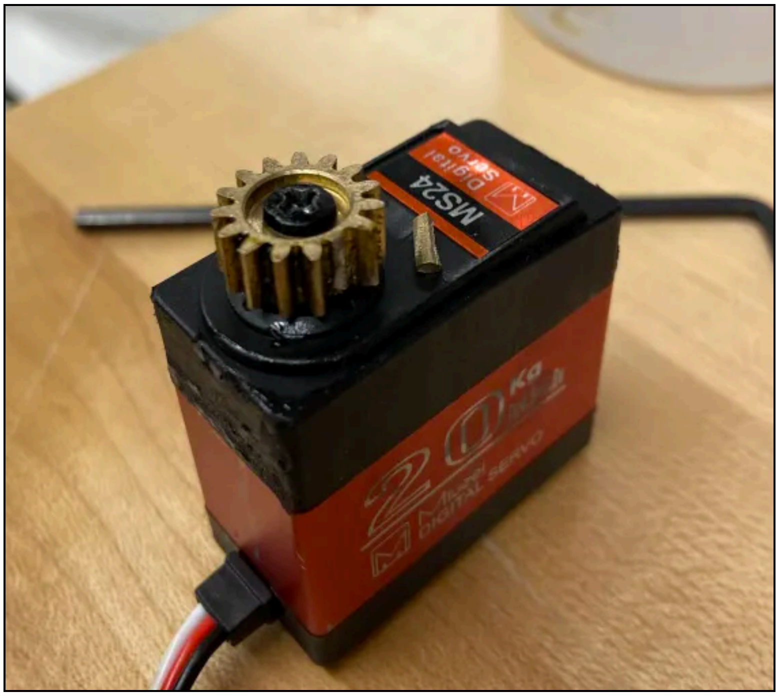

Figure 21: Pinion Gear with Sheared Tooth Following Impact Testing

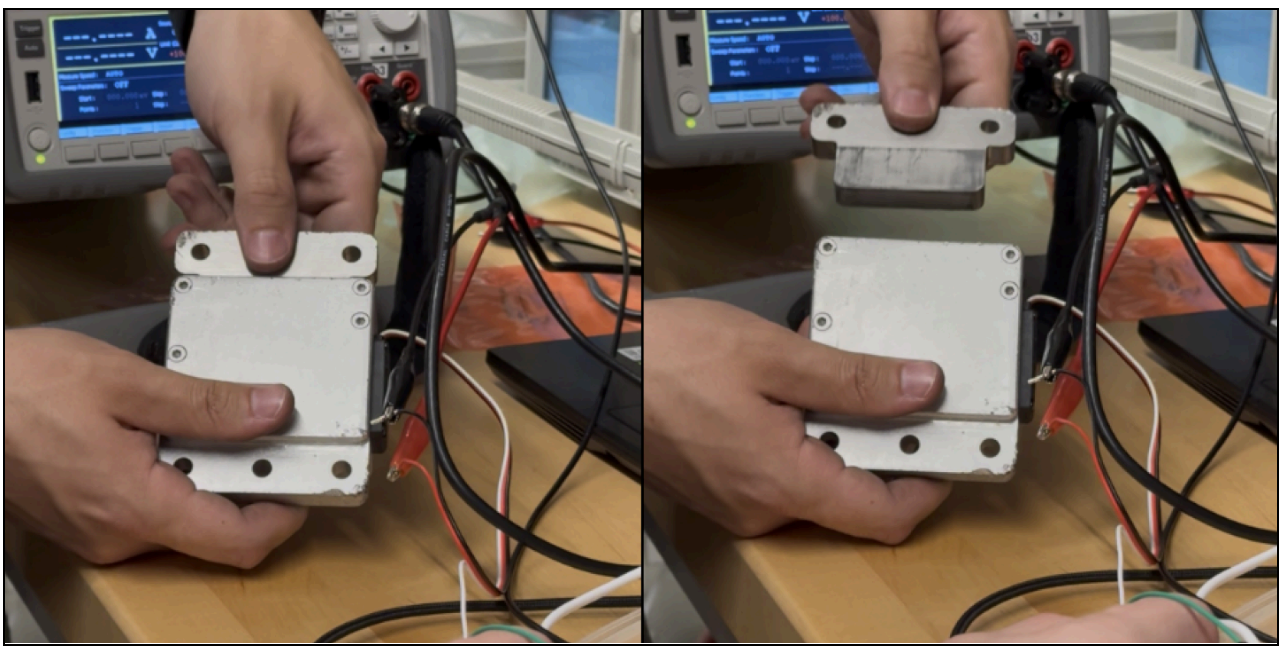

Figure 22: Drop-off Servo Actuation Test After Impact Testing

Full Collar Assembly

The complete collar system integrates all mechanical and electronic subsystems into a rugged, field-deployable unit designed for long-term wildlife tracking. The structure is built around a durable fibre reinforced rubber belting strap, sized for bison, with pre-drilled holes for easy adjustment and hardware mounting.

The electronics and power systems in this prototype are enclosed in a 3D-printed battery box for demonstration purposes, designed to house seven SAFT LSH20 lithium batteries. This enclosure also contains the tracking electronics board, including the GPS module, Argos satellite transmitter, microcontroller, and power regulation circuitry. The internals of the enclosure are then potted with epoxy resin to ensure optimal durability and water resistance. The enclosure is fastened to the collar using stainless steel hardware and provides a sealed environment to protect sensitive electronics from dust, moisture, and impact.

Future improvements include machining the electronics box from nylon to improve durability without hindering GPS and data transmission abilities.

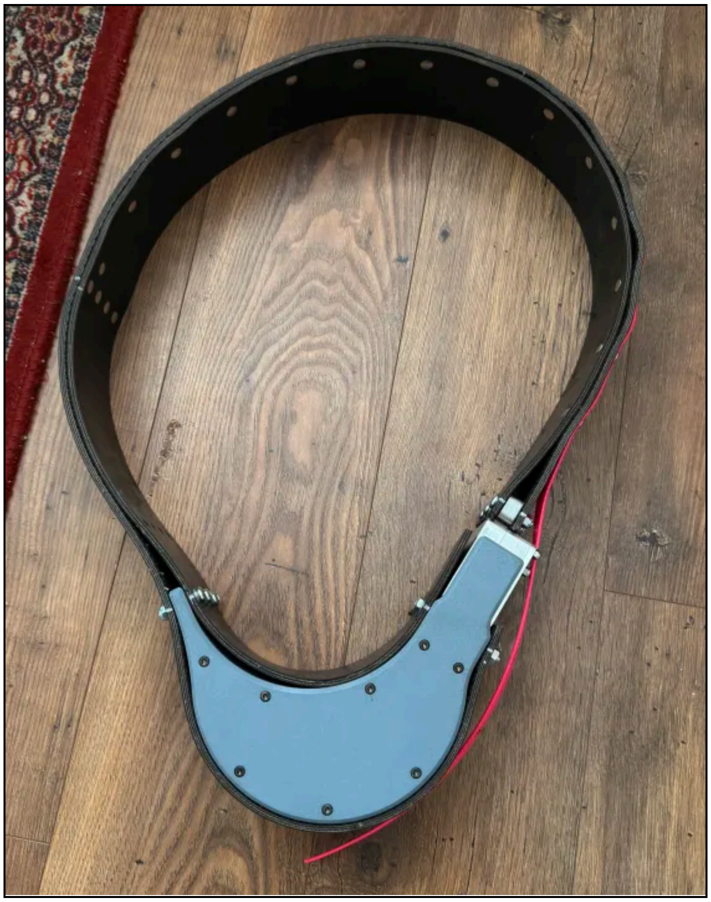

Figure 23: Full Mechanical Design Integrated into Bison Collar

Electrical

The electronics must support a GPS module, a satellite communications module, and a microcontroller, and facilitate communication between them. There must also be a servo controller, a battery measurement system, and a battery management DC-DC converter to convert the battery voltage to a voltage the rest of the components can use.

All components will be mounted on a 30x40mm PCB with wires connecting to the batteries, servo, and the external port.

Microcontroller

Microcontroller Selection

The microcontroller is an important part with many requirements. We require that the microcontroller have two UART ports, a deep sleep mode for low power consumption, an ADC for battery measurement, and two additional GPIO pins to control the servo and the satellite communication module.

Table 8: Microcontroller Requirements

Satellite Communication Requirement	Description
Variable Sampling Rate	A variable sampling rate is key for battery management.
UART Communication	The module will use UART to communicate with the host microcontroller.
Power Draw	The GPS must be power-efficient.
Temperature Resistance	The housing must survive harsh Albertan environments: temperature ranges of -40 to 40°C.
Four-Year Life Span	The device must last a minimum of four years of regular use.
Low Voltage Alarm	The device must measure battery voltage and have an emergency procedure.

Given the requirements, a decision matrix was made to decide the best microcontroller.

Table 9: Microcontroller Decision Matrix

Criteria	Weight	LPC802	SMT32	MSP430	ATtiny1614
Power Draw	5	5	2	4	1
Cost	3	3	3	1	5
	Total	34	19	23	20

According to the decision matrix, the LPC802 is the clear choice, and that choice is reinforced by the excellent developer board available for the microcontroller.
We purchased a development board for the LPC802 so we can test the code before we manufacture a PCB. The code is expanded upon in the software section.

Pinout

A detailed pinout of the microcontroller is shown in *table 10*.

Table 10: Microcontroller Pinout

Pin	Symbol	Description	Connected to
1	PIO0_16/ADC_3/ACMP_I4	IO PIO0_16 — General-purpose port 0 input/output 16. ACMP_I4 — Analog comparator common input 4. ADC_3 — ADC input 3.	Signal pin for servo control
2	*PIO0_17/ADC_9*	IO PIO0_17 — General-purpose port 0 input/output 17. A ADC_9 — ADC input 9.	Connected to pin 15 on KIM2 (EXT_PWR_ON)
3	PIO0_13/ADC_10	IO PIO0_13 — General-purpose port 0 input/output 13. A ADC_10 — ADC input 10	Connected to pin 6 on KIM2 (EXT_WKUP)
4	PIO0_12	IO PIO0_12 — General-purpose port 0 input/output 12. ISP entry pin. A LOW level on this pin during reset starts the ISP command handler.	Connected to pin 5 on KIM2 (KIM_INT/USR_I01)
5	RESET/PIO0_5	IO RESET — External reset input: A LOW-going pulse as short as 50 ns on this pin resets the device, causing I/O ports and peripherals to take on their default states, and processor execution to begin at address 0. The RESET pin can be left unconnected or be used as a GPIO or for any movable function if an external RESET function is not needed. I PIO0_5 — Gener	Reset LPC pin on Jlink flashing output
6	PIO0_4/ADC_11/TRST	IO PIO0_4 — General-purpose port 0 input/output 4. In ISP mode, this pin is the U0_TXD pin (for single supply devices). In boundary scan mode: TRST (Test Reset). A ADC_11 — ADC input 11.	Connected to pin 38 on KIM2 (LPUSART_RX)
7	SWCLK/PIO0_3/TCK	I SWCLK — Serial Wire Clock. SWCLK is enabled by default on this pin. In boundary scan mode: TCK (Test Clock). IO PIO0_3 — General-purpose port 0 input/output 3.	SWCLK LPC pin on Jlink flashing output with upwards bias through 100KOhm resistor
8	SWDIO/PIO0_2/TMS	IO SWDIO — Serial Wire Debug I/O. SWDIO is enabled by default on this pin. In boundary scan mode: TMS (Test Mode Select). I/O PIO0_2 — General-purpose port 0 input/output 2.	SWDIO LPC pin on Jlink flashing output with upwards bias through 100KOhm resistor

9	PIO0_11/ADC_6/WKTCLKIN	IO PIO0_11 — General-purpose port 0 input/output 11. A ADC_6 — ADC input 6. I WKTCKLKIN — This pin can host an external clock for the self-wake-up timer. To use the pin as a self-wake-up timer clock input, select the external clock in the wake-up timer CTRL register. The external clock input is active in sleep, deep-sleep, and power-down modes.	Connected through a 100KOhm resistor to the Reset KIM2 pin on the Jlink flashing output and pin 2 on the KIM2 (USR_NRST)
10	PIO0_10/ADC_7	IO PIO0_10 — General-purpose port 0 input/output 10. A ADC_7 — ADC input 7.	Not connected
11	PIO0_15/ADC_8	IO PIO0_15 — General-purpose port 0 input/output 15. ADC_8 — ADC input 8.	Not connected
12	PIO0_1/ADC_0/ACMP_I2/CLKIN/TDI	IO PIO0_1 — General-purpose port 0 input/output 1. In boundary scan mode: TDI (Test Data In). A ACMP_I2 — Analog comparator input 2. I CLKIN — External clock input.	Connected to battery power through: 2 capacitors for battery power filtering and a resistor bridge between first a 4.6 MOhm to then a 10Mohm resistor that is in paralel with a .1uF capacitor
13	PIO0_9/ADC_4	IO PIO0_9 — General-purpose port 0 input/output 9. In ISP mode, this is the U0_TXD pin (for dual supply devices) A ADC_4 — ADC input 4.	Connected to pin 14 (RXD) of the SAM GPS module
14	PIO0_8/ADC_5	IO PIO0_8 — General-purpose port 0 input/output 8. In ISP mode, this is the U0_RXD pin (for dual supply devices). A ADC_5 — ADC input 5.	Connected to pin 13 (TXD) of the SAM GPS module
15	VDD	If VDDIO is present, VDD is the supply voltage for the I/Os on the right side of the package and the core voltage regulator. If VDDIO is not present, VDD also supplies voltage to the I/Os on the left side of the package.	Connected to output power of TP563021D5JT through .1uF and .01uF capacitors after 3x22uF capacitor filtering from dcdc converter
16	VSS	Ground	Ground
17	PIO0_7/ADC_1/ACMPVREF	IO PIO0_7 — General-purpose port 0 input/output 7. A ADC_1 — ADC input 1. ACMPVREF — Alternate reference voltage for the analog comparator.	Not connected
18	VREFP	VREFP — ADC positive reference voltage. Must be equal or lower than VDD.	Connected to output power of TP563021D5JT through .1uF, .01uF and 10uF capacitors after 3x22uF capacitor filtering from dcdc converter
19	PIO0_0/ACMP_I1/TDO	IO PIO0_0 — General-purpose port 0 input/output 0. In ISP mode, this is the U0_RXD pin (for single supply devices). In boundary scan mode: TDO (Test Data Out). A ACMP_I1 — Analog comparator input 1.	Connected to pin 37 on KIM2 (LPUSART_TX)
20	PIO0_14/ADC_2/ACMP_I3	IO PIO0_14 — General-purpose port 0 input/output 14. A ACMP_I3 — Analog comparator common input 3. A ADC_2 — ADC input 2.	Signal pin for servo control

Voltage Sensing

The collar requires a sensor to detect the voltage of the batteries. This is used to inform the customer of the remaining battery life and to ensure the collar will be released from the animal before the batteries die. An ADC was used to sense the voltage of the batteries but due to the limitation of the microcontroller, voltage above 3.3V cannot be measured, so a voltage divider was needed. Due to the low power requirements a very high resistance (10MΩ and 4.7MΩ) was selected to reduce current draw. A capacitor was also added in an attempt to reduce fluctuations in the reading. This high-resistance voltage divider ended up being pulled high by the microcontroller's ADC, invalidating our readings. The resistors were replaced with a lower resistance alternative (two 10kΩ), and the reading was stabilized.
This fix results in the idle current draw of our board being higher than initially expected and requires more batteries to work in its current state.
A redesign has been drafted using a similar low-resistance voltage divider, but also with a MOSFET to turn on and off the reading, saving power.

Satellite Communication Network

Satellite Module Selection

The satellite communication network and corresponding module are a critical part of the project; all other electrical parts revolve around the support and communication of this module. For wildlife monitoring, there are two main competitors, Argos and Iridium.

Table 11: Satellite Communication Requirements

Satellite Communication Requirement	Description
Compact	The module must be able to fit on the PCB inside the housing
UART Communication	The module will use UART to communicate with the host microcontroller.
Power Draw	Must be power-efficient.
Temperature Resistance	The module must survive harsh Albertan environments: temperature ranges of -40 to 40°C.

Argos (specifically the new Kineis constellations and the KIM2 module) offers a lower up-front cost for the module, which is the primary expense of the collar. It also requires less power, allowing for fewer batteries. However, it transmits at a lower frequency than Iridium, requiring a larger antenna.

Iridium, on the other hand, has a higher up-front cost and requires more complex antenna electronics. It also consumes more power.

Considering these pros and cons, we decided to go with the KIM2 module using ARGOS for its simplicity and lower power requirement.

We do not have a quote for the price of the KIM2 module as it has not been officially released to the public yet. Due to this, we are currently using the KIM1's development board for our testing and will be using the KIM2 when we make the PCB. We have an estimate of the price of the KIM1's development board at $400, which our company reps have bought for us, but we will still include it in our budget.

Antenna

Due to the complexities and the iterative nature of antenna design, it was decided with our sponsors that antenna design would be out of scope.
For this project, KIM2 development boards were used for testing the electronics as they have an included antenna solution. KIM2 solder pads were put on the PCB for future integration.

GPS

GPS Selection

The GPS module must have a compact size with an integrated antenna to reduce complexity, low power consumption, voltage compatibility with the existing regulator, and a reasonable cost. These requirements are reflected in the decision matrix.

Table 12: GPS Module Requirements

Satellite Communication Requirement	Description
Compact	The module must be able to fit on the PCB inside the housing
UART Communication	The module will use UART to communicate with the host microcontroller.
Power Draw	The GPS must be power-efficient.
Temperature Resistance	The housing must survive harsh Albertan environments: temperature ranges of -40 to 40°C.

Table 13: GPS Module Decision Matrix

Criteria	Weight	SAM-M10	ZOE-M8	CD-PA1616D	L76L-M33
Size	5	5	2	5	2
Power Draw	3	5	4	3	1
Cost	2	1	2	3	5
Voltage Compatibility	5	Yes (1)	No (0)	Yes (1)	Yes (1)

	Total	47	26	45	28

Based on the decision matrix, both the SAM-M10 and the CD-PA1616D are nearly equivalent choices. The SAM-M10 offers lower power consumption but at a higher cost. The decision was made to allocate the budget towards improving the device's lifespan by selecting the SAM-M10.

We purchased a development board so we can test the GPS's functionality before we manufacture a PCB.

GPS Performance

During testing, our GPS module drew 12 mA during signal acquisition, taking an average of 30 seconds to lock in ~50% open sky. We considered this a reasonable worst-case condition, more obstructed than typical field environments but less so than a forest. In the more realistic conditions where bison usually roam (mostly open fields), faster acquisition and lower energy use are expected.

DC-DC

The DC-DC module must have a low power consumption and a reasonable cost, and we should be able to integrate the chip onto a PCB. Furthermore, the chip must accept the full voltage range of the LSH20 batteries (2-5V) and output a stable 3.3V with up to 800mA for transmitting.

Table 14: DC-DC Converter Requirements

Satellite Communication Requirement	Description
Power Draw	The DC-DC converter must be power-efficient.
Temperature Resistance	The DC-DC converter must survive harsh Albertan environments: temperature ranges of -40 to 40°C.

Table 15: DC-DC Decision Matrix

Criteria	Weight	TPS63031DSKR	ISL91107IINZ-T	TPS63021DSJT	ISL9110AIITNZ-T	ISL91110IRNZ-T7A
Pin Configuration	10	Yes (1)	No (0)	Yes (1)	No (0)	Yes (1)
Efficiency	5	1	3	3	2	3
Cost	2	4	5	2	3	1
	Total	23	25	29	16	27

Based on the decision matrix, the TPS63021DSJT is the best option as it has a convenient pin configuration and high efficiency. Furthermore, it is cheaper than the ISL91110IRNZ-T7A, which is also efficient but more expensive.

Servo Control

The servo control uses PWM from the MC and power from a MOSFET that is controlled by the MC. This is done because the idle draw of the servo is ~40mA, which would kill the batteries very quickly. When we want to unlatch the drop-off, the servo turns on the power, and the PWM controls the servo as seen in *figure 23*.

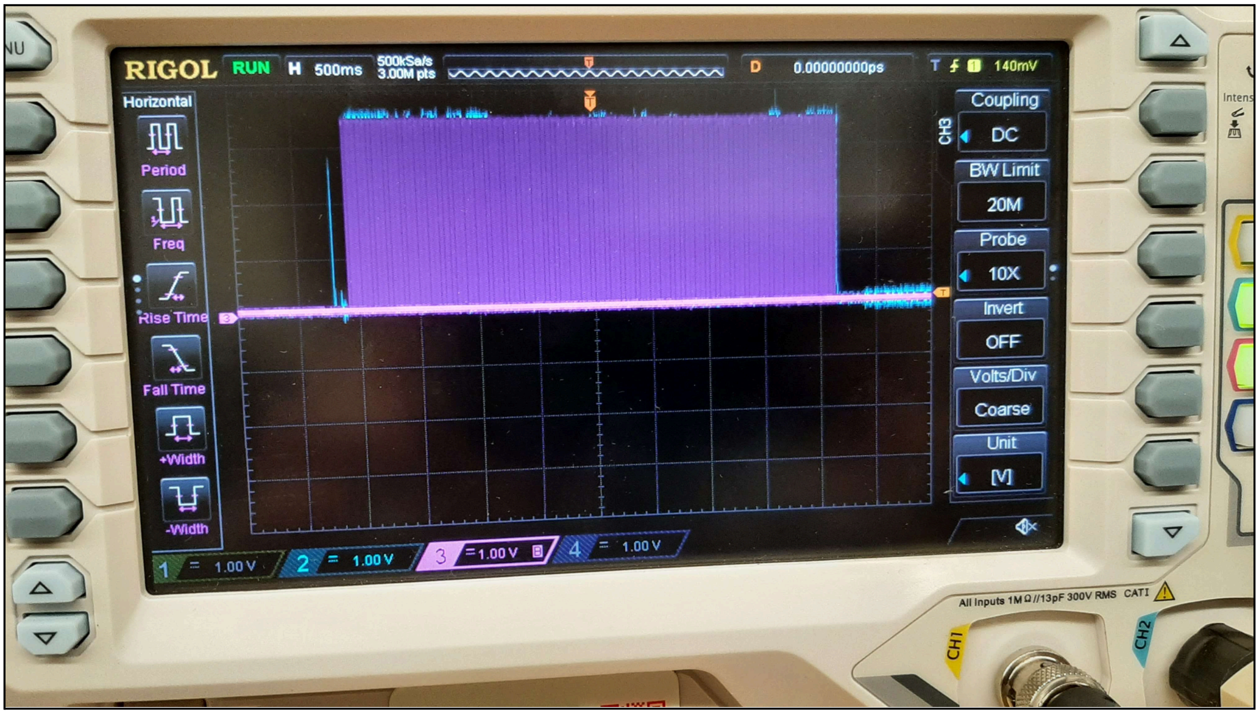

Figure 24: Servo Power and Signal

Estimated Energy Consumption

Energy consumption is a critical factor in the selection of all our components. Calculations must be made to ensure our collar will transmit throughout its lifespan. The main factor in how much energy we use is the frequency of our data transmissions. For each transmission, twelve GPS coordinates are in RAM. The energy consumption per transmission is calculated and extrapolated to estimate the battery life.

This was the initial calculation and estimate for the battery consumption. More realistic energy consumption figures can only be obtained through testing, which we did in future sections.

During the GPS on time, the microcontroller consumes 1mA of current, and the GPS consumes 13mA for ~33s every time we collect a GPS coordinate. This comes to 462 mAs.
During the transmission, the microcontroller again consumes 1mA of current, and the KIM2 module consumes 425mA for ~10s. This comes to 4260 mAs.

For each transmission, twelve GPS positions are required, so the total per transmission is 9804mAs per transmission. Factoring in the voltage converter's efficiency of 90% in this region, that number becomes 10893 mAs.

The idle current consumption of our components also needs to be calculated. In deep sleep mode, the microcontroller has a power consumption of 0.15uA, the GPS has a power consumption of 25nA, and the KIM2 has a consumption of 0.4uA. This totals to 0.821uA when factoring in the voltage converter's efficiency of 70% in this region.

Each of the batteries can supply 13Ah. The current plan is to have two or three, but the decision will be made after we have tested the power consumption of the PCB to ensure the functionality of the system. For the time being, two batteries are used for the calculations, giving us a total of 26Ah of storage.

These numbers give the result of 5.88 transmissions a day, which can be rounded down to 4 transmissions a day or one every 6 hours, giving the customer coordinates every 30 minutes.

Tested Energy Consumption

The actual energy consumption of the board was tested by putting a multimeter in series with the battery pack, and the values were recorded every second. The graph over 200 seconds can be seen in Figure 22.

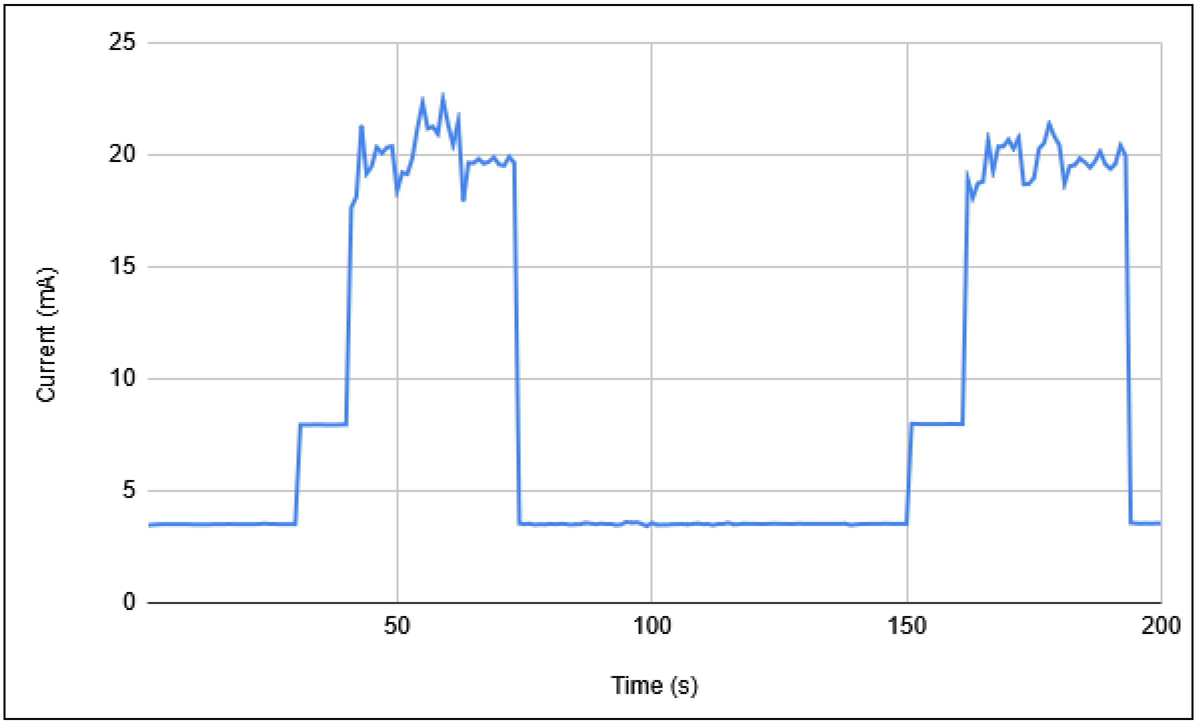

Figure 25: Current Consumption Data

A current consumption of ~3.5mA is consumed when the board is asleep, the GPS and KIM are off, and the microcontroller is in power-down mode. This is, unfortunately, much higher than expected and points to some kind of current loss in the system. In future designs, the issue will be corrected and the consumption will be in line with previous estimates, ~0.2mA. The current consumption of the board idle per year would be 30.66Ah.

When the board wakes up, it draws ~8mA for 9 seconds, then after it turns the GPS on, it draws 20mA for 32 seconds. The power consumption of the board is higher than expected, but the GPS power consumption is within spec. The current consumption of a single GPS acquisition every day for a year is 0.05556 Ah. A standard setup where the GPS is polled every 15 minutes would consume 5.33 Ah.

Unfortunately, due to supplier delays, we were unable to get the KIM2 satellite transmission module running in our project. We were able to get the KIM1 working, but the difference in power consumption is a major factor so, for this section, we are going to use the data sheets from the suppliers to estimate the power consumption.

The KIM2 module to transmit first needs to go through a warmup phase where it consumes 6 mA for ~2 seconds. It then transmits for ~0.5s per coordinate collected, where it consumes 290mA.

After all the messages have been sent, the module switches to reception mode, where it warms up again at 6mA for ~2s. It then receives messages at 75mA for ~5s.

Assuming the transmissions are batched in groups of 12, we can calculate the current consumption. For one GPS coordinate a day, it comes to 0.01807 Ah. For our hypothetical situation of a GPS position every 15 minutes, it would consume 1.7347 Ah.

Given these numbers in our hypothetical situation, we can expect to consume 37.72 Ah a year. With the suggested original layout of four LSH20 batteries, we can expect a battery life of 1.38 years. This is below our initial goal of four years, but this is mainly due to the high idle consumption. If this issue is fixed, the project shows promise in being very competitive in its battery life. Our current prototype collar has seven batteries, which would give us a life of just about 2.4 years..

PCB Design

The PCB we created is a single 30x40mm double-sided circuit board that enables all the functionality required for our collar. This board mounts the KIM2 satellite module, SAM-M10 GPS module, TPS63021DSJT DC/DC converter, and the LPC802 microcontroller, along with all the supporting components. There were many considerations when designing the PCB:

Varying trace widths were implemented to accommodate the servo motor's high inrush currents of up to 2.5 A, helping to prevent overheating and potential board failure. Debug ports were included to facilitate easy troubleshooting, with several pins placed on key UART communication lines to enable monitoring of data flow between the microcontroller, GPS, and satellite modules. Additionally, dedicated flashing pads for a J-Link system were incorporated to allow convenient programming of the LPC802 microcontroller's firmware. However, our current design also has a few oversights:

Dedicated ground planes should have been included to improve the performance of the GPS and satellite transmissions, although the GPS was still able to acquire a signal with relative ease despite their absence. The DC/DC converter layout, while functional, could be significantly optimized, as the current traces for the filtering capacitors are overly long and thin instead of following the manufacturer's recommended layout with larger signal planes for stable power delivery. Additionally, the MOSFET net for the servo power was incorrectly connected due to rotated nets in the design software, an issue that was identified during assembly and resolved by unconventionally mounting the component to achieve the correct connection.

Software Specifications

Architecture

The system architecture keeps all components in sleep mode, with the microcontroller waking periodically to collect GPS coordinates before returning to sleep. Once enough data points have been collected, the data is transmitted via satellites. The customer can control both the transmission and GPS update frequencies.
See the flow chart for a more in-depth description.

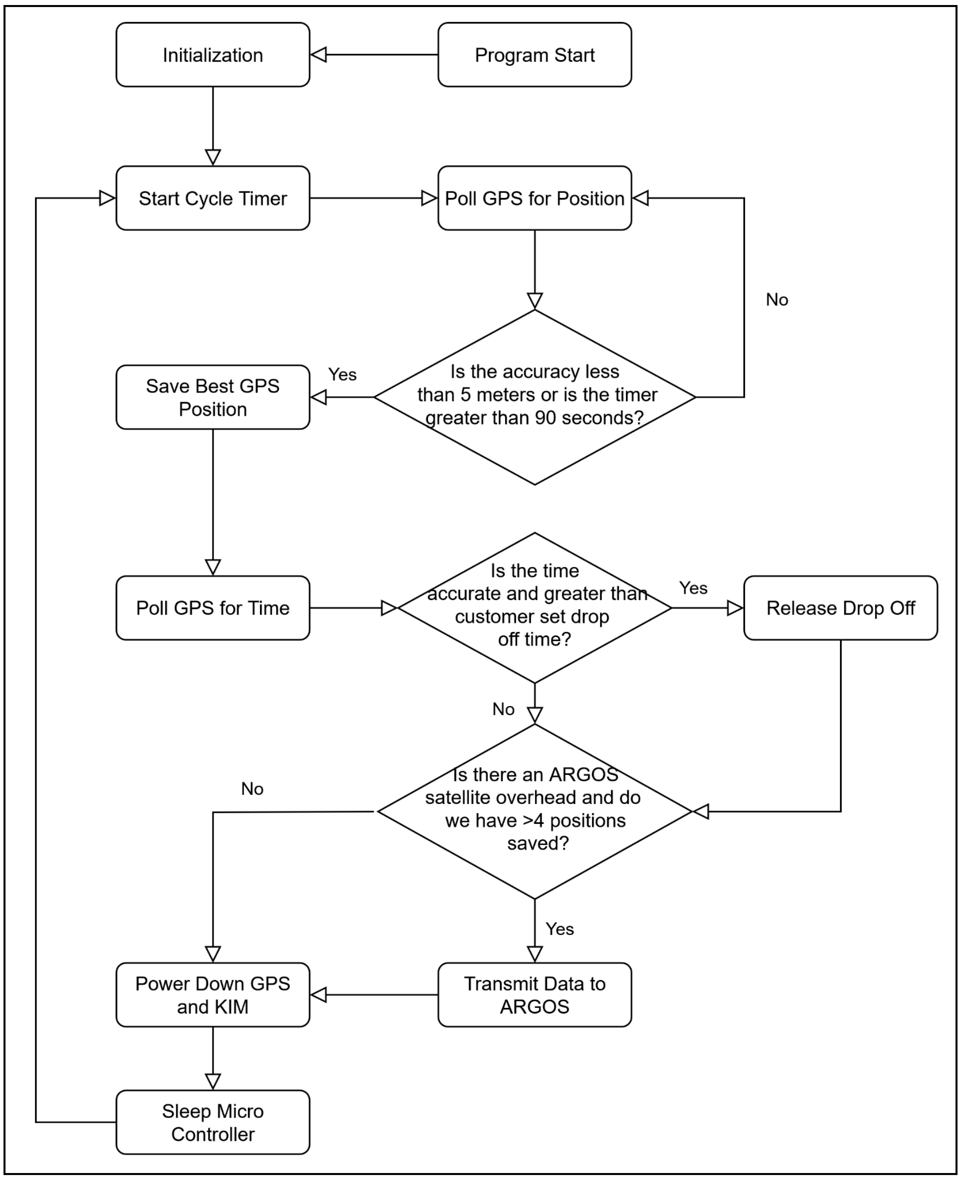

Figure 26: System Architecture Flow Chart

Satellite Communication

The satellite transmission control consists of a timing mechanism that references the previous transmission, a configurable transmission rate parameter, and a satellite visibility check. UART serves as the communication interface between the system and the host microcontroller.
The system stores coordinates in RAM before transmission to ARGOS, initiated by the host microcontroller.

Table 16: Satellite Communication Requirements

Satellite Communication Requirement	Description
Variable Sampling Rate	A variable sampling rate is key for battery management.
UART Communication	The module will use UART to communicate with the host microcontroller.

GPS

The GPS control includes a timing mechanism based on a configurable coordinate rate parameter and GPS module settings. UART is used for communication with the host microcontroller.
The GPS module is configured for fast warm starts and high accuracy.

Table 17: GPS Requirements

GPS Requirement	Description
Variable Sampling Rate	A variable sampling rate is key for battery management.
UART Communication	The module will use UART to communicate with the host microcontroller.

Servo Control

The servo control utilizes two GPIO ports for operation. One creates the PWM signal to move the servo into a latched or unlatched state, and the other controls a MOSFET that powers the servo on and off for power saving. Actuation occurs based on a customer-defined time parameter, a low battery, or a command received via satellite.

Battery Management

The microcontroller manages power consumption by disabling the satellite transmission module and GPS when not in use and entering a low-power state. Battery life is determined by the customer-selected transmission frequency. An onboard ADC in the host microcontroller measures battery voltage during satellite transmission to capture worst-case power usage. If the battery voltage is dangerously low, the collar can be automatically dropped, and a transmission sent to the customer, alerting them.

Table 18: Battery Management Requirements

Battery Management Requirement	Description
Temperature Resistance	The housing must survive harsh Albertan environments: temperature ranges of -40 to 40°C.
Four-Year Life Span	The device must last a minimum of four years of regular use.
Low Voltage Alarm	The device must measure battery voltage and have an emergency procedure.

Sleep Configuration

The goal of the sleep configuration is to reduce the power draw of the board while keeping the time the board has to stay awake low.

The microcontroller has to keep its position in the program, and it has to retain its RAM. This makes the choice of power state simple; power-down mode was selected. This state keeps the RAM powered and tracks the position in the program.

The power-down state of the GPS was similar; the GPS was set to a low power state where it holds its RAM for a warm start. The low power mode was not activated as it slows the acquisition time too much. The module is configured to wake up on UART input.

The KIM2 module is similarly configured to a low power mode, but it is woken up by an interrupt connected to a GPIO pin.

Transmission Format

Satellite transmission format takes the form of a single continuous hex string containing multiple data points. For example, the coordinate packet 04F2DC68B6D39ED51D5211DA000021AB0FFF can be decoded to several fields: the Time of Week (04F2DC68) is a 32-bit unsigned integer representing GPS time of week in milliseconds, the Longitude (B6D39ED5) is a 32-bit signed integer in 1×10^{-7} degrees, the Latitude (1D5211DA) is a 32-bit signed integer in 1×10^{-7} degrees, the Horizontal Accuracy Estimate (000021AB) is a 32-bit unsigned integer estimating GPS fix accuracy in millimeters and the Battery Voltage (0FFF) is a 16-bit unsigned integer indicating measured battery voltage.

By encoding the data in raw binary and representing it as a hex string, the transmission uses significantly fewer bytes compared to human-readable formats than JSON or ASCII. This efficiency is crucial since RAM is a valuable resource in our microcontroller; storing such data in less efficient formats would use up storage quickly and require more frequent satellite communication, thus increasing power consumption.

Map Demonstration Software

To demonstrate how the data is transmitted and decoded, a custom Map Demonstration Software was developed in Python using the Streamlit and Folium libraries, serving as a visually appealing interface for decoding and plotting test GPS data recorded in prior tests. The tool takes raw hexadecimal strings (e.g., 04F2DC68B6D39ED51D5211DA000021AB0FFF) from previous system tests, then, using Python's struct library, unpacks them into human-readable data such as longitude, latitude, accuracy, and battery voltage, while also converting GPS Time of Week into the localized time for easier interpretation.

Users can either input a single hex string directly into a text box, generate a custom hex code from artificial data, or upload a CSV file containing a batch of hex strings for bulk processing of historical data. Once decoded, the GPS coordinates are plotted on an interactive map using Folium. The application color-codes the markers in a gradient so that the most recent points appear more vibrant, providing a clear sense of movement over time, and each point includes a detailed pop-up with time, latitude, longitude, accuracy, and battery voltage. This app can be launched via a simple batch file and provides a clear visual aid during the capstone presentation. Showing how users would be able to interact with our product to obtain relevant insights.

Testing

A testing setup was made, including the main board, a temporary battery pack made of two AA batteries, and a dev board acting logger, so we could record the board's output without having to transmit via satellite. The setup is shown in Figure 24.

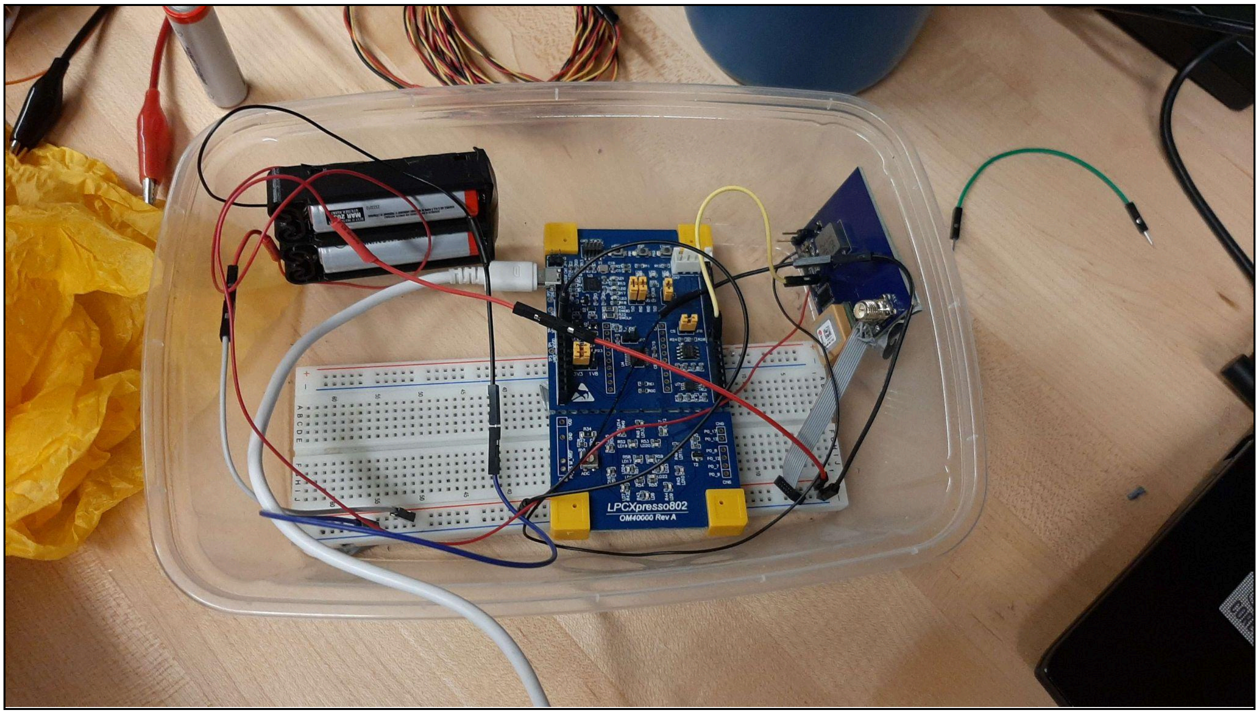

Figure 27: Electrical/Software Testing System

Using this setup and a computer to log, data was collected on various walks and hikes while using a backpack to hold everything together. The best data collected is shown in Figure 25, using the map demonstration software.

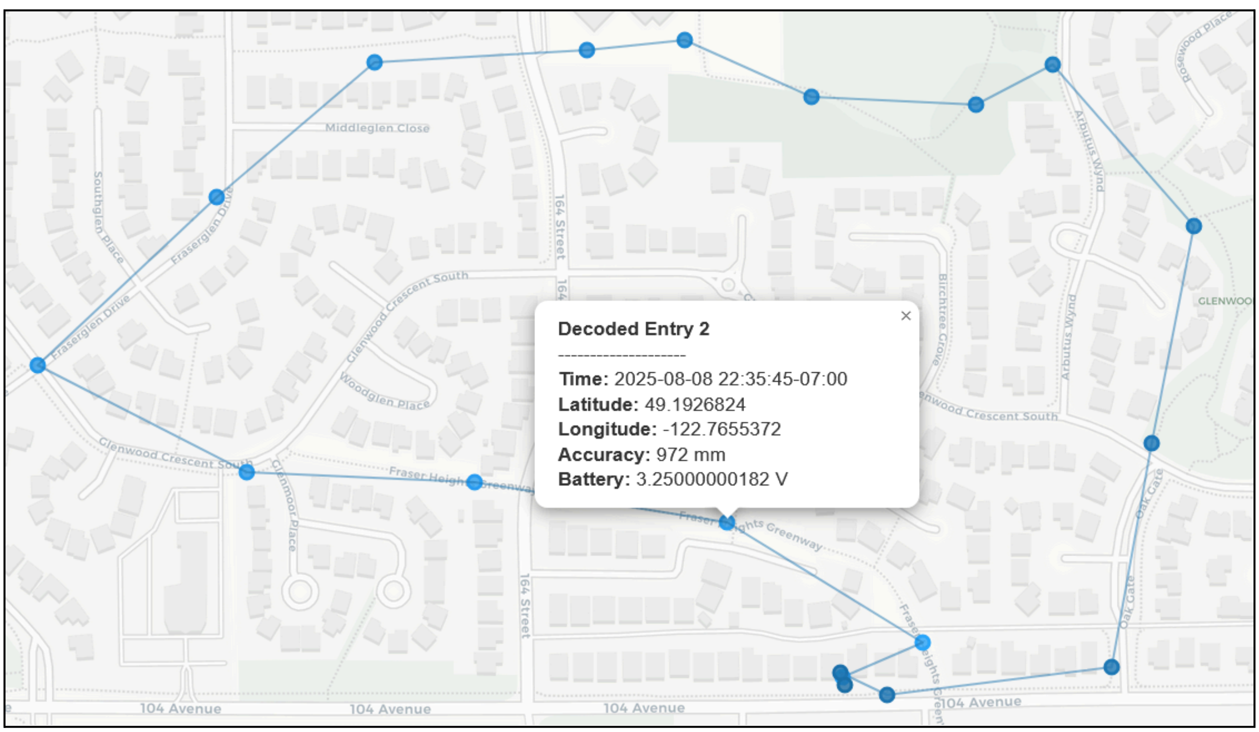

Figure 28: GPS Walk Data

Conclusion

The BisonTrack GPS tracking collar has been developed to meet the demanding requirements of long-term bison monitoring in harsh environmental conditions. Through careful integration of mechanical, electrical, and software systems, the design addresses the durability and reliability challenges that have limited the effectiveness of existing market solutions. The robust housing and seatbelt-style drop-off mechanism ensure the collar can withstand extreme physical stress while maintaining consistent performance.

The electrical system, built around the LPC802 microcontroller, SAM-M10Q GPS module, and Kinéis satellite communication, balances accuracy with power efficiency to support a multi-year operational lifespan. Incorporating a low-power architecture and configurable sampling rates allows the system to optimize battery use while maintaining the frequency of position updates required for effective conservation work. The drop-off mechanism adds an additional layer of reliability, enabling safe removal at the end of the service life or in the event of low battery voltage.

This project provides a cost-effective, long-lasting solution for wildlife biologists and conservationists working to protect bison populations. By ensuring consistent location tracking and robust field performance, the BisonTrack collar supports data-driven decision-making in habitat management and disease prevention. Ongoing testing and refinement will further validate the system in real-world conditions, ensuring it is ready for deployment as a dependable tool for bison conservation efforts.

Looking ahead, several opportunities exist for improvement. Further optimization of power consumption could significantly extend battery life toward the four-year target, particularly by addressing idle current draw in the satellite and GPS modules. Alternative materials for the drop-off's internal gearing could increase resistance to impact damage, and a ground plane could be incorporated to improve GPS and ARGOS transmission accuracy. Additionally, earlier access to final Kinéis hardware would have allowed more precise integration and testing, potentially streamlining the development process and reducing design iterations.

References

This document was written with the assistance of ChatGPT (OpenAI, 2025) to improve clarity and structure.

[1] "Bison Bellows: What's Wallowing All About? (U.S." *National Park Service*, 2 November 2017, https://www.nps.gov/articles/bison-bellow-1-28-16.htm. Accessed 2 March 2025.

[2] "IUCN Red List of Threatened Species." *IUCN Red List of Threatened Species*, https://www.iucnredlist.org/species/2815/123789863. Accessed 2 March 2025.

[3] "Wallowing-Resistant and Self-Releasing GPS Collar for Bison Herd Tracking" *Wright Collars*, 2025, https://docs.google.com/document/d/1Ndlgi6s8bGm-C2fMBlCbdvHsE97r6jCtevRjtXnVPRM/edit?usp=sharing

[4] "Products Liability." *Science Direct*, 2019, https://www.sciencedirect.com/science/article/pii/B9780128132401000261. Accessed 2 March 2025.