

Red Newt Racing Tracker Team

Real-Time GPS Baton Tracker for the Seneca 7 Relay Race

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Community Partner: Newt Racing (Ian Golding)

Project Location: Tompkins County & Ontario County, NY



1. Executive Summary

The Seneca 7 is an annual 77.7-mile relay race organized by Red Newt Racing and The Finger Lakes Running Club (Ian Golding, Race Director) that encompasses Seneca Lake, drawing over 2,000 participants from 16+ states across 300+ competing teams annually. The event raises approximately \$20,000 per edition for more than 20 local non-profit organizations. The existing race uses slap bracelet logging at checkpoints, but provides no real-time location data, no runner performance metrics, and no automated handoff detection, placing a significant operational burden on volunteers and leaving participants without the analytics that contemporary endurance events routinely deliver. Cellular coverage along substantial portions of the race is insufficient for standard GPS uplinks, requiring an alternative communication architecture. Therefore, the project aimed to design, fabricate, and deploy a reusable IoT baton that tracks runner GPS position at 30-second intervals, detects baton handoffs via an integrated push-button and streams live data to race officials and racers through a custom web interface. LoRaWAN (Long Range Wide Area Network) was selected as the communication protocol for its ability to transmit data up to 10-16 km in a rural line of sight condition without cellular infrastructure. Functional requirements for the project included evaluating device weight, enclosure dimensions, durability and volunteer usability, designed in direct consultation between the race organizers and runners.

Development of the tracker had three main iterations. The first prototype (The Minion) established the component sizes, and how they fit into the enclosure. It also confirmed basic TTN connectivity and GPS acquisition. The second generation prototype (The Newt) improved the button reliability and flattened the top of the form for a slimmer design. Following these iterations, a user study of 45 runners informed the future form factor decisions: 65% of participants do not carry items in their pockets during races/runs, and the waist pack was the most preferred mounting method (42%) if they did carry the weight on the body, which lead the project to adapting a multi-configuration attachment system. The final prototype (Grips) integrated ergonomic grip ridges, carabiner loop, weather protected ports, and a woven rear strap into a matte PLA enclosure slim enough to be handheld or body mounted for use. Gateway infrastructure evolved from fixed-elevation concepts to a mobile multitech MTCDT-L4N1 LoRa gateway powered by a portable 99.9 Wh power station and transported in a support racing vehicle on leading the race field.

The current baton iteration (Grips) successfully transmitted GPS coordinates and handoff events to the TTN at 30-second intervals. A custom streamlit application subscribing via MQTT rendered a live map and runner statistics accessible from desktop and mobile browsers, with CSV export for post-race analysis. End-to-end data flow was verified through campus runs and community 5K deployment. Field testing near Seneca Lake confirmed mobile gateway connectivity. MATLAB signal analysis documented received signal strength as a function of baton-to-gateway distance, providing baseline range characterization data. The limitations of the project included the enclosure compactness, and gateway range. The compact V3 enclosure measurably degraded antenna performance reducing effective transmission range, which was a tradeoff for the ergonomic value. Full-course gateway range was not completed within the project timeline. Additionally, the current enclosure was not tested against formal IP ingress standards, and since a single prototype was produced it has not been tested for multi-device network behavior at race scale. Priority recommendations for the next development cycle include redesigning the enclosure to restore antenna clearance without sacrificing the form factor, and conducting a systematic LoRaWAN coverage survey of the full race course. Additional explorations should also include testing the multi-unit set to test for network loading, extending the streamlit platform with post race summaries and year-over-year comparisons, and taking the baton tracking system to other Red Newt Racing events in rural or wilderness tracking across the Finger Lakes region.

2. Engineering Social Context

A. Project Purpose and Motivation

Newt Racing, operated by race director Ian Golding and headquartered in Ithaca, NY (Tompkins County), organizes the Seneca 7, an annual 77.7-mile relay race that circumnavigates Seneca Lake, starting and finishing at the New York Welcome Center in Lakefront Park, Geneva (Ontario County). The event mobilizes over 300 teams of seven runners, drawing more than 2,000 participants per year from as many as 16 states, with registered participants traveling from as far as Texas and Colorado [1].

The current race uses a simple slap bracelet as the baton. This arrangement provides no real-time positional data for race officials, no per-runner performance metrics, and no automated detection of baton exchanges between runners. These limitations make race monitoring operationally demanding for volunteers and deprive participants of the data-rich experience that modern sporting events increasingly offer. Our proposed project addresses this gap directly: the design and development of a reusable, baton-form-factor GPS tracker that records location at one-minute intervals, detects baton handoffs between runners, and calculates individual performance statistics, all while maintaining reliable connectivity across the rural and semi-rural terrain around the lake.

The core engineering challenge is connectivity. Cellular coverage along the Seneca Lake shoreline, especially on the eastern shore through Yates and Schuyler counties and the western shore between Watkins Glen and Dresden, is inconsistent. Standard GPS devices that depend on cellular data transmission fail in these low-coverage zones. The system will therefore incorporate LoRa (Long Range) radio communication, a Low-Power Wide-Area Network (LPWAN) protocol capable of transmitting data up to 10–16 km in rural line-of-sight conditions without reliance on any cellular network. LoRaWAN operates in unlicensed ISM frequency bands, eliminating recurring spectrum licensing fees and enabling a private, purpose-built network for the event [2].

B. Community Partnership — Newt Racing



Ian Golding is the owner of Finger Lakes Running Company (Ithaca, NY) and serves as race director for the Seneca 7 under the Newt Racing organization. Golding brings direct operational expertise in large-scale relay event logistics, including the management of 11 staggered wave starts, 20 designated exchange points distributed across four counties, and coordination of over 200 race-day volunteers. This firsthand knowledge of course geography, exchange-point infrastructure, and participant safety requirements informs the functional specification for the tracker system.

Golding provides: (1) access to course topology data and exchange-point coordinates; (2) knowledge of which course segments present the greatest coverage challenges; (3) input on acceptable device weight, size, and durability given that runners carry the baton for legs ranging from approximately 10–12 miles; and (4) organizational reach to communicate the system to the 300+ competing teams. In return, we aim to design and produce a deployable, reusable asset that Newt Racing can field every year, removing the cost of single-use timing chips and providing race officials with a real-time live map of all active batons.

Seneca 7 already raises approximately \$20,000 per race edition, distributed equitably to more than 20 local non-profit partner organizations including Habitat for Humanity, the Geneva Family YMCA, and Family Counseling of the Finger Lakes. A tracker system that reduces per-event operational overhead and enhances race safety directly protects the financial sustainability of a community fundraising mechanism that benefits organizations serving the permanent residents of Ontario, Seneca, Yates, Schuyler, and Tompkins counties.

C. Broader Impact Beyond the Seneca 7

3.1 Scalability to Other Newt Racing Events

Newt Racing organizes multiple events beyond Seneca 7. A reusable, event-agnostic tracker, lightweight, self-contained, and off-grid capable is directly transferable to any relay or point-to-point race that Newt Racing operates, regardless of location. GPS-based athlete tracking systems have demonstrated strong adoption across professional and amateur sport since their introduction in the late 1990s [3,4], with the market now accessible to high school-level programs as cost barriers have declined. The tracker developed here targets a category that remains underserved: sub-professional endurance relay events in rural environments, where commercial GPS vests designed for team sports are impractical in price and form factor.

3.2 Low-Cost Off-Grid Tracking Platform

The design's combination of satellite positioning and LoRa communication constitutes a general-purpose, low-cost off-grid tracking architecture. IoT-based GPS systems that fuse multi-constellation GNSS with LPWAN radio have been demonstrated to achieve sub-meter positional accuracy in field conditions using commercially available microcontrollers and filter algorithms [5]. GPS operates independently of any cellular infrastructure, performing with greater reliability in open rural terrain than in urban environments where signal multipath is prevalent [6]. LoRaWAN complements this by providing the data uplink in locations where no cellular tower is within range or conditions that describe significant portions of the Seneca 7 course.

Beyond racing, this architecture has direct applicability in: wilderness search-and-rescue personnel tracking; agricultural equipment monitoring on farms without cellular coverage; and low-cost conservation or wildlife monitoring programs in the Finger Lakes region. The LoRaWAN standard is recognized by the International Telecommunication Union (ITU) as an LPWAN standard, and its adoption is expanding globally across smart agriculture, environmental monitoring, and smart city applications across all sectors with presence in the Finger Lakes region. The hardware platform developed for this project therefore represents a meaningful, locally validated proof-of-concept for a broader class of off-grid IoT tracking deployments.

3.3 Race Safety and Participant Experience

Relay race safety depends on the ability of race officials to locate runners in real time, particularly in the event of an injury or a runner failing to arrive at an exchange point within an expected window. The current baton provides no such visibility. A GPS tracker that transmits location at one-minute

intervals gives race officials and medical support personnel a persistent, course-wide situational picture. This aligns with established practice in professional sport, where GPS wearables are used not only for performance analysis but specifically for injury risk monitoring and athlete welfare, enabling coaching staff to identify when an athlete is underperforming relative to personal benchmarks as an early indicator of physical distress.



For the 2,000+ participants, per-runner performance metrics, pace, distance covered, split times delivered post-race through the tracker data represent a tangible improvement in the quality of the race experience. Studies in sports performance analysis establish that isolated distance or speed data is most valuable when contextualized against individual and team benchmarks. The baton tracker is positioned to provide exactly this: automated, per-leg statistics that participants can review after each edition of the race, year-over-year.

2. Review of Related Work

The most directly relevant precedent comes from the Spring 2025 MAE 4220 tracker team, whose final project produced a user-friendly, low-power LoRaWAN mapping device intended for use by non-technical volunteers. The device featured a compact weather-resistant enclosure, real-time GPS and LoRaWAN status display via an OLED screen, manual SD card data logging in JSON format, TTN integration via MQTT, and a graphical user interface accompanied by a user manual and assembly guide. Our team aims to replicate this core technical foundation while tailoring the design specifically for the Seneca 7 relay race.

Two key limitations of the tracker team's design are worth noting in the context of our application. First, the form factor, while handheld, was optimized for passive data visualization during slow-paced activities such as walking, not for the physical demands of competitive running. Our design requires a more streamlined enclosure suited for either wearing or secure handheld use during a relay exchange. Second, the tracker team's field testing was conducted primarily in urban areas near existing gateway infrastructure. The Seneca 7 course, by contrast, includes rural stretches and gorge areas with limited or no gateway coverage, requiring our system to maintain reliable IoT connectivity in environments with significant signal dead zones.

A. Critiques of Consumer Devices

Several consumer products in the sports tracking space provide additional technical context for our design. MYLAPS uses RFID timing chips to deliver high-accuracy split and lap time measurements across a wide range of racing disciplines, including marathons, triathlons, and cycling events. ChronoTrack similarly employs disposable RFID tags affixed to race bibs to capture and relay real-time results, primarily for road races and longer-distance events. The Garmin Forerunner 570 is a full-featured athlete wearable offering an 18-hour battery life alongside an extensive suite of health and performance metrics, including VO2 max, HRV status, race time prediction, and body battery monitoring. The SPOT Trace is a satellite-based consumer tracking device that transmits location updates via text or email at selectable intervals ranging from 2.5 to 60 minutes, with additional features such as movement alerts and low battery notifications.

Each of these products informs specific aspects of our design. MYLAPS and ChronoTrack highlight the precision achievable through RFID-based timing, though this technology has been explicitly excluded by the Seneca 7 staff due to past reliability issues in the gorge areas along the course. The Garmin Forerunner demonstrates the viability of a wrist-worn form factor for athlete tracking, an approach worth considering for improving ease of transfer between runners. The SPOT Trace underscores the potential of satellite-based GPS as a connectivity solution in remote environments, offering a more reliable alternative to gateway-dependent LoRaWAN transmission in areas with limited infrastructure coverage.

B. User Studies

A user study was conducted with a sample size of 45 participants, 25 female and 20 male, to directly inform the physical design decisions of the baton. The survey was structured around three core questions targeting the carrying habits and body-mounting preferences of long distance runners, as these factors would directly influence how the baton would need to be designed to be practical and non-intrusive during an active race. The first question asked whether runners carry items in their pockets during long distance running. A strong majority, 65% of respondents, indicated that they do not, while only 35% said they do. This result alone signaled that designing the baton as an exclusively pocket-based device would fail to serve the majority of the target user base.

However, rather than abandoning pocket compatibility entirely, the data suggests that a pocket friendly form factor should be one option among several, not the primary design constraint. The second question asked whether runners hold their phones during a race or run. Nearly half of the respondents, 47% said yes, while 33% said no, and 20% reported using their pockets. This indicates that a significant portion of runners are already accustomed to holding or securing a handheld object while running, which supports the viability of a baton that can be gripped, clipped, or strapped to the body without causing significant disruption to the runner's natural motion. The third question directly asked how runners prefer to strap items to their body. The fanny pack or waist pack with the most popular method, at 42% followed by arm straps at 20%, back-mounted solutions at 19%, and pocket carry at 15%. The distribution of responses across multiple mounting styles confirmed that no single attachment method dominated runner preference, which reinforced the need for a baton design that supports multiple securing configurations rather than being optimized for only one.



Figure 2: User Studies InfoGraphic. This demonstrates the necessity for straps to improve holding

Taking these results together, the baton V4 was developed with an adaptable attachment system. Strap-based mounting options were prioritized to ensure compatibility with common running accessories such as hydration vests, waist packs, and arm bands. At the same time the overall form factor was refined to be slim enough to fit within a pocket for runners, or held comfortably in the hand with additional grips on the design. Particular attention was directed towards female athletes, who made up the majority of the study sample and who, in general, face more limited built-in storage options in standard athletic apparel. By accounting for this directly in our design process, we aimed to ensure that the baton is a practical and accessible tool for all participants in the races, regardless of their preferred carrying method or gear they already run with.

C. Excluded Technologies

Per explicit guidance from the Seneca 7 staff, RFID and general radio frequency identification systems are excluded from the design. Prior race implementations of RFID technology proved unreliable due to signal dead zones in the gorge areas surrounding the course, resulting in significant data loss. In keeping with this direction, the team will not incorporate RFID or any comparable identification technology into the baton design.

3. Project Scope

A. Design Objective

Our team will design and implement an IoT-based tracking system to continuously capture real-time GPS data (recorded at one-minute intervals) for runners competing in the Seneca 7 race on April 26th. The system will feature custom smart batons capable of passively logging runner timestamps, rankings, pace, and instantaneous velocity, alongside active mechanisms such as buttons and switches to register baton handoffs between runners, with all data streaming in real time to race officials, organizers, and teams. To ensure reliable connectivity around Seneca Lake, we will evaluate existing TTN gateway infrastructure along the route and deploy portable gateways at the front and rear of the race field wherever coverage gaps exist. Our target completion date is April 12th, allowing sufficient time for staff approval and preliminary testing with the Seneca 7 team ahead of race day.



Figure 3: Rendered Form Factor of Baton V1. This includes the Red Newt Racing Logo, for product branding, and race specific identification.

B. Design Vision

Our relay baton project follows an iterative product development process encompassing stakeholder interviews, hardware development, and validation testing to meet the requirements outlined by the Seneca 7 organizers. The key development benchmarks are outlined below.

1. **Form Factor Exploration.** The team will begin by fabricating prototypes across multiple form factors based around a traditional baton design. These prototypes will include clip-on components, strap-based designs that attach around the waist, shoulder, or hand, and variations manufactured using different materials such as PLA, ABS, and TPU. Additional designs with varying grip styles will also be explored.

Concurrently, surveys and user feedback sessions will be conducted with members of the Cornell Running Club and other active runners to systematically evaluate usability strengths and weaknesses. The collected feedback will help inform the selection of the most effective and practical form factor for the race environment.

2. **Initial Electronic Prototype.** With a form factor selected, we will develop a preliminary electronic prototype integrating the core components necessary for basic system functionality, establishing a foundation for subsequent hardware iterations. Basic functionality would include: connecting to The Things Network (TTN) LoRaWAN network,

determining GPS location, pressing a button to note exchange, and calculating distance run per runner.

3. **Full-Scale Prototype V1.** The first full-scale prototype will be developed using CAD, further informed by the chosen form factor, translating the initial electronic design into a structured, manufacturable physical enclosure.
 - a. **Verification Testing & Physical Iteration.** The prototype will undergo initial verification testing to confirm it meets defined technical requirements, including proper GPS data packaging and reliable transmission at specified distances from the nearest gateway. Findings will drive targeted improvements to the physical design.
4. **IoT Code Infrastructure.** In parallel, we will develop the embedded software for the SparkFun Feather M0 board, leveraging skeleton code from prior tracker teams as a baseline and extending it to support our specific data collection, transmission, and baton handoff detection requirements.
5. **TTN Gateway Infrastructure.** Our team will establish backend connectivity by setting up the baton so that it can connect to any public gateway along the Seneca 7. The team will also register all devices within The Things Network (TTN), ensuring the system is properly configured for LoRaWAN-based data transmission across the race route.
6. **Basic GUI Development.** A lightweight online interface will be developed via Streamlit to decode incoming data packages and display results in a human-readable format, supporting internal testing and early stakeholder demonstrations. The user interface will be significantly improved to meet the operational needs of racing staff, incorporating most desired race attributes, including pace, handoff events and time, displayed clearly on an interactive map.
7. **Full-Scale Prototype V2.** Incorporating all lessons learned from verification and validation testing, a second full-scale prototype will be produced that unifies improvements across form factor, electronics, and participant interaction into a refined, race-ready device.
 - a. **Validation Testing.** The full-scale prototype will be deployed and operated in both rural (Trials around Seneca Lake/ Beebe Lake) and urban (Cornell Campus/ Ithaca/ Geneva) environments to validate real-world system performance under conditions representative of the Seneca Lake race route.
8. **Staff Presentation & Approval.** The completed system will be formally presented to the Seneca 7 staff and racing crew for hands-on review, feedback, and final approval ahead of race day.

4. Technological Development

A. Gateway Methods

Three primary gateway configurations were prototyped and explored to enable reliable communication between the baton tracking device and the network throughout the duration of the race. The first concept involved leveraging satellite communication to maintain continuous connectivity independent of geographic location. The second concept proposed mounting a fixed gateway at a high-elevation location to maximize line-of-sight coverage across the race path. The third concept centered on developing a mobile gateway system powered by portable energy sources and transported by a vehicle trailing the race participants. The satellite approach, while theoretically sound, presented several practical limitations. Satellite systems require an unobstructed line-of-sight to the sky, which becomes unreliable in areas with dense tree coverage such as the terrain surrounding Seneca Lake. Beyond the environmental constraints, satellite communication introduces higher costs, increased latency, and a more complex setup process. Given the project timeline and the coordination that would have been required with race organizers to implement and fund such a system, this option was not feasible for the current implementation and was set aside early in the design process. The high-elevation gateway concept was explored more seriously, and through understanding the geographic context of the race, the city of Dundee was identified as a strong candidate site due to its elevation advantage relative to the race path. Outreach was conducted through corporate partners in an effort to secure a deployment location from a willing property owner or business in the area. However, a reliable site could not be secured within the project timeline. For these reasons, this approach was also discontinued.

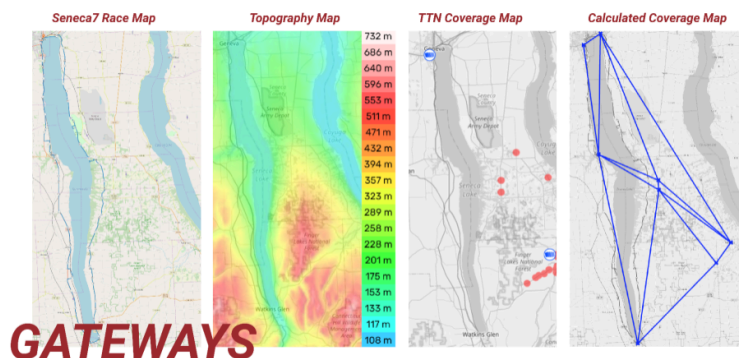


Figure 4: Gateway Mapping. The Seneca Seven race is shown on the left, indicating the regions runners will need to be covered by. The Topography map conjunctly showcases the elevation around these areas which helps to identify regions of high elevation above the race route. The third and fourth images are a TTN current coverage map, which shows both gateways, and areas where signal is high, which covers a large portion of the second half of the race.

The mobile gateway concept was ultimately selected as the primary design direction. The gateway used in this system is the MultiTech MTCDDT-L4N1, an LTE Cat 4 programmable gateway with integrated LoRa connectivity. This device requires an input of 9–32 V DC at approximately 700 mA. The first iteration of the power system sourced from a graduate research lab consisted of a 12 V battery connected to a 72 W DC-DC step-down converter, which fed into a 410 W Schumacher DC-to-AC power inverter. While this configuration successfully powered the gateway, the overall assembly was large, heavy, and poorly suited for mobile deployment. To improve portability, the team transitioned to the JIYHF P100 portable power station, which provides both a 110 V AC outlet and a 12 V DC output, with a capacity of 99.9 Wh. A single unit supports approximately 13 hours of continuous operation. Two units were procured to provide redundancy and extend the total

operational window. As a secondary backup, a PowerDrive PWD120 car outlet inverter was identified as a solution for directly powering the gateway from a vehicle, allowing for indefinite runtime when a car is available. The entire system is deployed within a vehicle that follows the race participants, maintaining consistent proximity to the baton device and reducing the effects of environmental signal obstruction throughout the race.



Figure 5 & 6: Mobile Race Gateway. This includes the SIM Card TTN Gateway with the Portable JIYHF P100 Power Station fitted below. This device would be placed in the window of the followers car or stationary along the runner path at a central position.

B. Electromechanical Design

Our device underwent three major electromechanical design iterations: “the Minion,” “the Newt,” and “the Finalist.” “The Minion” was the first iteration of the baton that served as the first attempt at containing and fixturing all components for initial testing. “The Newt” was the second iteration of our baton that slimmed the design and improved internal fixturing for the electrical components. With this in mind, two separate designs were developed to prioritize these individual objectives, with V2a optimizing internal fixturing and V2b for improved ergonomics. Despite developing the 3D models, key design contradictions with the assembly forced another mechanical design integration. “The Finalist” is our final design that compiled our learnings from form factor testing with the completed electronics to design a device ideal for the race.

Previous iterations aimed to optimize mechanical fixturing, ergonomics, and reliability for the final V3 Baton design. “The Minion” was the first 3D-printed and assembled alpha prototype design, given the name due to the blue and yellow color scheme. This included a larger casing that left room for the ICR battery case, the Feather M0 board, the antenna, and the other miscellaneous electronics. “The Newt” aimed to improve the electronics from the previous device and slim the mechanical casing to prepare for our final, beta prototype. For the electronics, our team swapped the MKT GPS Module with a standard NEO-M8 GPS Module that connected via TX/RX and added heat shrink to the inside of the button to improve reliability. With these changes, different fixturing was required for the device to work properly. For the mechanical design, our team conducted user testing to converge on a slimmer design that meets an outer diameter between 1.5 and 2 inches. With the two major design solutions for the external casing, two different mechanical designs were created to meet both requirements. First, V2a was designed to optimize the fixturing methods for the button and the feather board for high-reliability in usage. Second, V2b was designed to meet the ergonomics requirements established by the user testing and reduced the external diameter to ~1.5 inches. With these designs completed and the electronics working, a design review occurred to determine the relevant features such as target ergonomics, water-proofing, and discreteness to adapt for the final, beta prototype.

“The Finalist” served as the first full-scale, electromechanical design with fully usable mechanical design, sensor functionality, and internet connectivity. The final design includes the ergonomic grips, slimmer design, a carabiner loop, covered access ports for weather-proofing. These parts were 3D-printed in matte PLA plastic, a woven strap was added on the back to improve contact, and all parts were compiled into the device as tightly as possible.

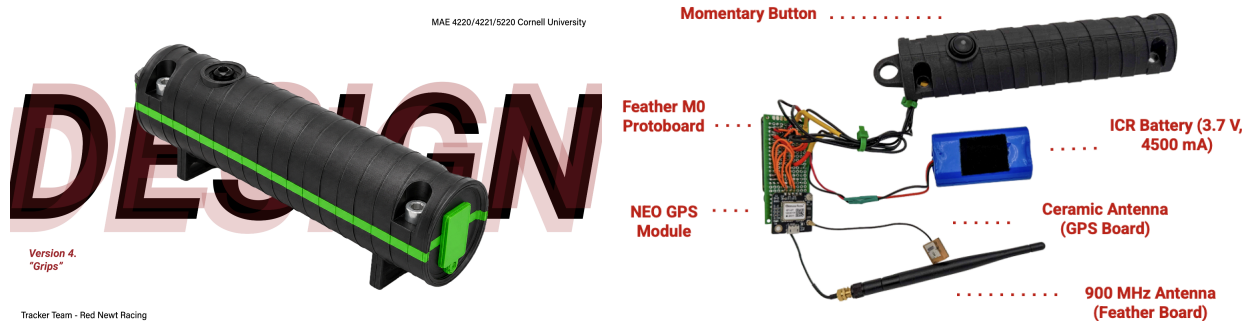


Figure 11 & 12: Physical Form Factor for “The Finalist” or Baton V3. This device is used for all verification and validation tests, specifically the Seneca7 race with Marathon Runners and the Belle Sherman 5k

C. Baton Software and Streamlit UI Design

Our software components consisted of one stack on-board the Feather M0 within the baton, and a secondary stack in GitHub for displaying outputs through a custom Streamlit app. The baton integrated coding systems from previous in-class labs to send a unique Baton ID, Latitude, Longitude, and Button Pressing to the TTN Console. The Streamlit app uses a unique MQTT listener to stream data from the TTN Console to a live application on the internet (accessible through both desktop and mobile). This structure is intentionally streamlined to limit streaming delays and ensure packages are sent every 30 seconds, and additional information such as SSR and RSSI are provided for troubleshooting hardware.

Each baton continuously broadcasts LoRaWAN data packets at 30-second intervals via LoRaWAN communication, using digital input buttons and GPS sensing to capture runner data. Collected data will flow from the baton through TTN gateways, into cloud-based databases, and ultimately be retrieved by the GUI for post-processing and display. Digital buttons will serve as the primary mechanism for logging relay handoffs between runners, functioning as simple logic gate inputs connected to a digital pin on the microcontroller. For positional tracking, our team will explore improving GPS resolution beyond the microcontroller's native capabilities, potentially through the integration of a dedicated GPS breakout board such as the NEO-M8. Given the scale and sensitivity of the data being collected, the team has used basic encryption to protect data integrity throughout transmission and decoding on the TTN Console.

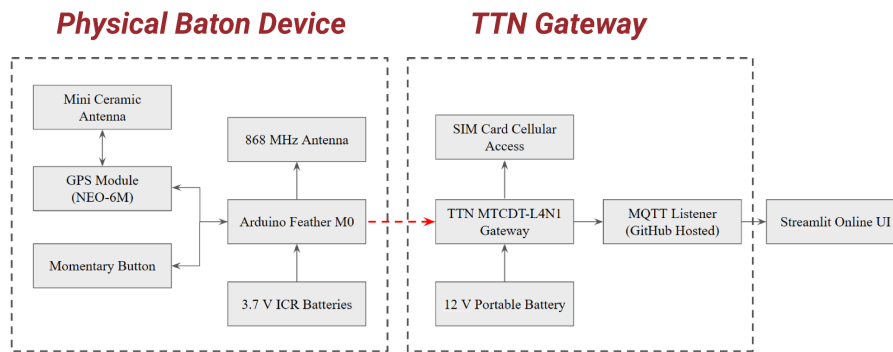


Figure 13: Block Diagram for Electronic Data Collection Inputs to UI Outputs with TTN Connection. The full-scale relay baton system is composed of three interconnected layers: the physical baton hardware, the network transmission infrastructure (TTN), and the backend data processing and visualization platform (GUI). Together, these layers form a continuous pipeline from raw sensor data collection at the runner level to real-time display for race officials and staff.

	baton_id	buttonPressed	lat	lon	rsi	time	
	0	1	5	42.4835	-76.4928	-14	2026-05-01 17:38:21+00:00

Figure 12: An example of a post-processed packet sent via LoRaWAN from the baton

After data is received to the TTN Console, the data is processed and displayed through a custom [Streamlit app](#) hosted in a GitHub repository. An MQTT listener accesses the TTN Console through a username and password for the Console, and the data is processed with a standard Python script to display GPS data, button press activity, and historic baton data. The UI uses caching to store the transmitted data across websites, meaning anyone with access to the application can visualize historic data and newer updates. Two buttons are provided at the top of the UI, with one for resetting the data (“Clear All”) and one for exporting the historic data as a .CSV file (“Export All”).

Figure 12: Operational Streamlit UI with Baton V3 (“The Finalist”) during initial verification testing In-Field

D. System Testing (Baton, Gateways, & UI)

Testing the mobile gateway revealed partial limitations to the approach depending on the geographic context. When deployed on a test run near Seneca Lake, the gateways can successfully connect to the baton, but the extent of this connection was not yet fully developed. The gateway

strength was large, but additional testing would need to be performed to determine the distance a baton can be from the gateway to consistently track the location. Given that the baton will be between 1-5 miles away from the car during the Race, we believe this will not be an issue, especially given the outdoor environment, however, testing on race day will illuminate gaps in coverage which can be further explored in the next generation of designs.

Running across campus with the baton, pressing the button every couple of minutes, and observing the output in the GUI served as the final verification test for the alpha prototype before further converging on a final design for race day.

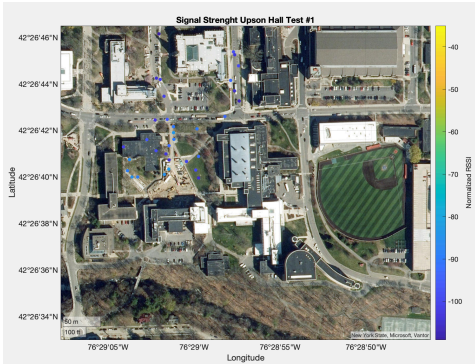


Figure 13: Signal drop-off during Validation Testing of the Beta Baton Design (processed in MATLAB)

Further testing was conducted during the next race we participated in, the Belle Sherman 5K. In this environment, there were fewer natural obstructions, such as trees and uneven terrain caused by extreme elevation changes, allowing our team to collect another set of data to better identify the limitations of the current device. For this test, a gateway was stationed at the blue square shown in Figure 15 before the race began. After the race, the data was compiled, and we found that only two data points were successfully received through The Things Network. This led to our next major technical observation: with the current setup, the baton and gateways can only reliably communicate when they are within approximately 600 feet of one another.

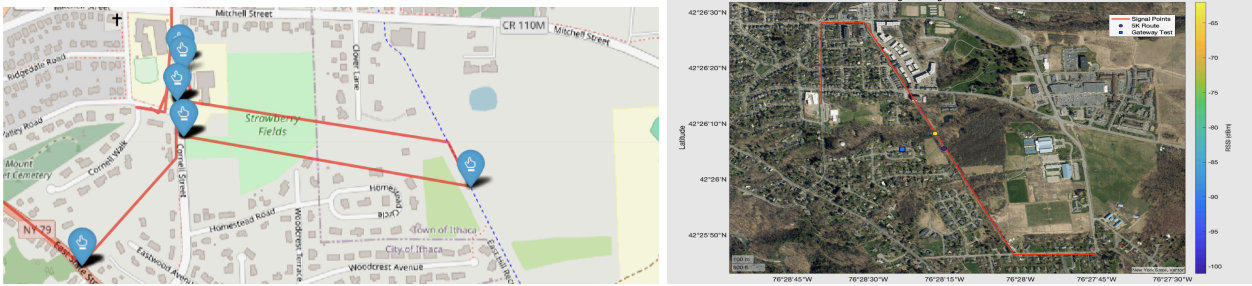


Figure 14 & 15: GPS Signal and Button Press Graph & Signal Strength Identification Graph for the Belle Sherman 5k race.

4. Next Steps for Development

The next team tasked with advancing the system should work towards full race-scale deployment at multiple races in the Finger Lakes. Here they are sequenced by technical priority and build directly on the design trade-offs and testing gaps identified during the project cycle.

The most significant technical limitation of the current prototype is the degradation of LoRaWAN transmission range caused by antenna compression within the V3 enclosure. The next enclosure iteration should allocate dedicated clearance volume for the antenna or evaluate an external stub antenna routed through a sealed port. Range benchmarking should follow any enclosure change, targeting consistent packet reception at distances representative of the baton-to-gateway separation expected during the race (1–5 miles in open rural terrain).

A systematic LoRaWAN signal survey along the complete 77.7-mile course should be conducted prior to the next race deployment. This involves driving the route with the mobile gateway and a transmitting baton device while logging received signal strength (RSSI) and packet success rate at regular intervals. Segments with coverage gaps, particularly gorge sections and forested eastern-shore stretches, should be flagged for supplemental gateway positioning or relay infrastructure.

The current enclosure provides basic weather resistance but has not been tested against any formal ingress standard. Given the outdoor race environment and exposure to rain, sweat, and potential drops, a minimum IP54 rating is recommended. This can be achieved through silicone gaskets on all access ports, conformal coating of exposed PCB surfaces, and a revised lid retention mechanism that maintains a consistent seal under dynamic loading.

Only one Finalist unit was produced during this cycle. Race deployment requires one baton per competing team, meaning upwards of 300 simultaneous transmitting devices sharing TTN gateway bandwidth. A batch of at least 10 units should be fabricated and tested concurrently to characterize packet collision rates, TTN duty-cycle compliance, and gateway throughput under realistic load. Component costs and assembly time per unit should also be documented to inform procurement planning for full-scale production.

Structural components currently fabricated in matte PLA are adequate for prototype validation but are susceptible to UV degradation and impact fracture under sustained outdoor use. Transitioning to PETG, ASA, or injection-molded ABS for the enclosure body and cap would meaningfully extend device service life across multiple annual race editions. At the same time, the carabiner attachment loop should be load-tested to confirm it meets the dynamic forces expected during runner handoffs and carrying.

The current Streamlit application covers live tracking and basic handoff logging. The next development cycle should extend the platform with a post-race module delivering per-leg split summaries, team leaderboard rankings, and year-over-year performance comparisons. These features directly increase the value of the system for the 2,000+ annual participants and reduce the manual data processing burden currently placed on race staff after each event.

References

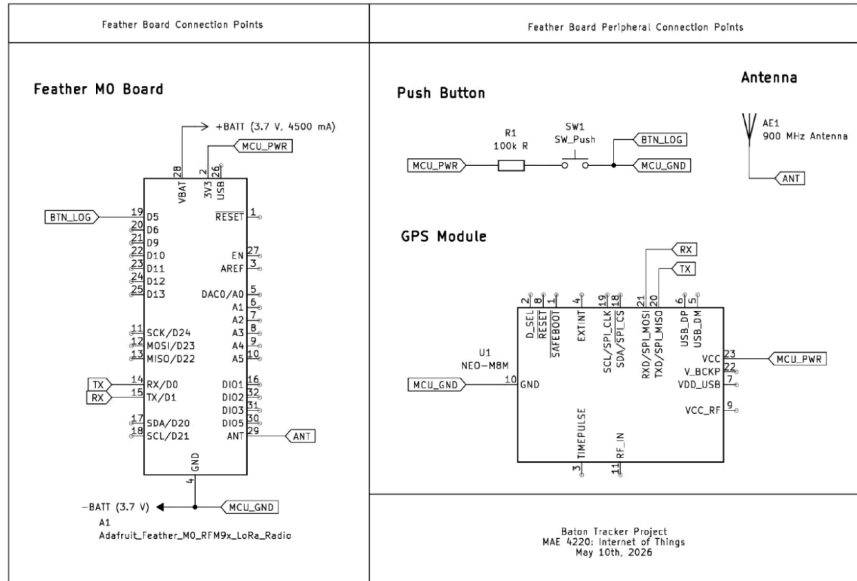
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Appendices

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Appendix A: Internal Electronics Configuration against the specific Schematic for the Baton V3.

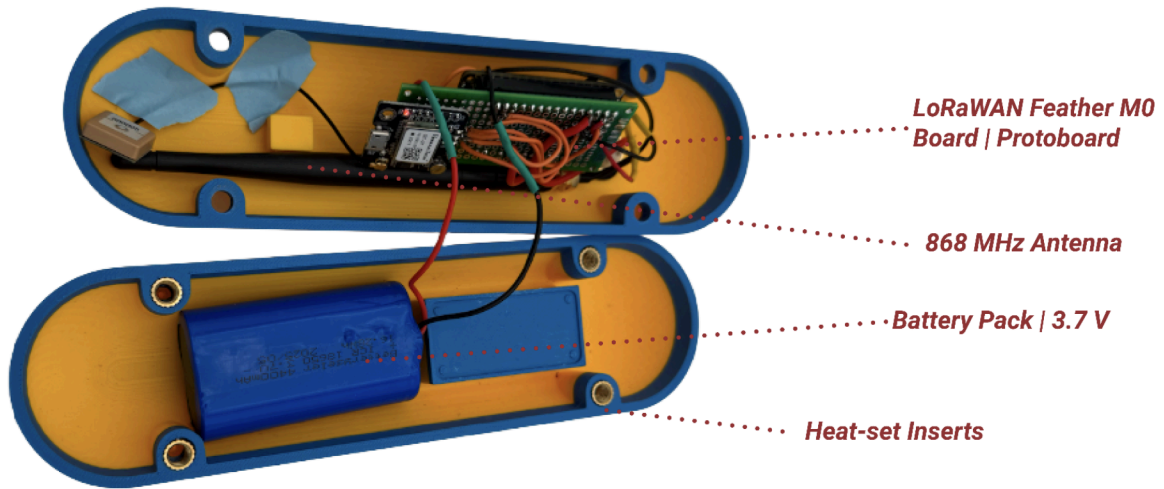
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Version 2.
"The Minion"

Tracker Team - Red Newt Racing

Appendix B: Physical Form Factor of "The Minion" or Baton V1.



Appendix C: Internal Electronics of "The Minion" or Baton V1



Figure D: Physical Form Factor of Baton V2a, or "The Newt," which is for optimal fixturing, especially a flat face for attaching the button.



Appendix E: Physical Form Factor of Baton V2b, or “The Newt,” which is ergonomically optimized.

RNR LIVE BATON TRACKER
NEWT RACING SENECA 7

MOTT CONNECTED
8 PACKETS 12 EVENTS

BATON ID: 01
BUTTON EVENTS: 12
LATITUDE: —
LONGITUDE: —
SIGNAL (RSSI): -26
PACKETS RX: 08
03:20:46 UTC - APR 17 LIVE

TEAM PHOTO
RACING TEAM
BELLA'S SQUAD

RECENT EVENTS

- Baton Press Detected** 12
03:20:46 - Campus Road
- Location Ping** 8
03:18:31 - Libe Slope
- Signal Acquired** 1
03:16:02 - Arts Quad

● CURRENT BATON
● BUTTON PRESS
— ROUTE TRACK

Appendix F: Future ideas for racer UI to replace the current Streamlit version