Dawg Tracker: A modern Low-Power and Wide Range Tracking device

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***Abstract*—In today's worlds, our animals are treated like family and, as such, we provide them with the same comfort and safety that we bestow on children. However, unlike children, you cannot simply call your dog or open up Find My Friends every time you want to check in on them. There are very few products on the market that allow for real time GPS tracking at a reasonable price despite a steadily growing market. We propose a novel pet tracking system that will deliver precise tracking up to 6 miles from your home. The system we have designed uses the latest technology in Radio-Frequency communication, LoRa, to provide users with an inexpensive, low-powered tracking solution. Our end product was comparable in size to available trackers and is the only device on the market that offers a fixed cost with no expensive subscription requirements. The bill of materials for our entire system is priced under $50, making it an effective, low cost dedicated pet tracker.**

I. Introduction

A common issue pet-owners face is discovering that their pet has escaped the house. To prevent this situation, we designed a low-power dog tracker using long range (LoRa) technology. Unlike other pet-tracking collars, our system implements a training technique by emitting a 20 kHz sound wave if the dog is found outside of a user-defined distance. For example, if the user would like to train their dog to stay within 60 meters from their owner, our device will detect whether the dog is within range and emit a high frequency sound if not.

To make the most use of our time, the development of the dog tracker was split into two phases. Phase I was designing the final PCB board with components that satisfied our low power and small footprint requirements. Once this was complete, we moved onto Phase II where we developed a bench prototype using breakout modules from Adafruit. This allowed us to verify the functionality of our system while waiting for the PCB and components to arrive. The final design of the PCB and bench-top prototype will both be discussed.

II. Background/Related Works

Almost every household pet these days is outfitted with a microchip. The microchip is a passive RFID module that allows vets and shelters to scan and identify the animal with the touch of a button. The issue with this is that many microchips either fail overtime due to normal wear and tear or never become useful because the dog isn't taken into the custody of Animal Control Services [1]. The IOT revolution make it possible for more people to get real time status updates on their furry friends. In Table. I, we show a comparison across many of the most popular active tracking devices. We will now discuss the various important features in each device to show how we arrived at our final design.

TABLE I
Comparison of other trackers on the market

Device	Price	Size (mm)	Battery Life (days)	Method	Limitations
Fi	$130+ $99/yr	66	<20	Bluetooth, WiFi, LTE-M	can't set safe range
Tractive	$50+ $96/yr	72	<6	LTE	battery life
Whistle GO	$130+ $99/yr	172	<20	WiFi, LTE	way too big, bad LTE service, no tracking within WiFi range, inaccurate battery life
Apple AirTag	$29	32	<365	Bluetooth	no real-time tracking, must be in dense area with lots of iPhones
Katzen tracker	N/A	30	N/A	LoRa	not for sale, must be within10km of gateway

The first option we will talk about is not a conventional dog tracking collar. The Apple AirTag was made to track everything from backpacks to car keys. The AirTag works over Bluetooth, connecting to any compatible iPhone within a 30ft range. This is a great option for people in dense, wealthy cities where iPhones are a popular choice, but would be completely useless in more spread-out suburbs. The AirTag is also one of the cheapest options at only $29.

There are many real-time dog location trackers currently on the market [2]. Almost all of them use the same base technology consisting of a GPS, which provides precise geolocation, and a GSM modem, which allows the tracker to send the information to the end user. The Fi is the best and most popular 'smart' dog collar on the market [3]. The collar works by fixing to three GPS satellites for extremely precise location tracking and then communicates with an owner's app by connecting to either WiFi or the cellular network. The cellular network is LTE-M, a form of low-power wide-area networks. It costs around $130 for the collar itself and then an additional $99 per year for the GPS and LTE-M plan. In addition, the device itself has an aluminum body and an IP68 Waterproof Rating, meaning that it can be submerged up to 1.5m. The battery life depends heavily on how the collar is being used. It ranges from up to 3months, for a dog that is always at home and connected to WiFi, to only 2 days, for a lost dog that needs real time location tracking [4].

The device that we took the most inspiration from is the Katzentracker. While not currently for sale, their parts list is mostly open source. They use a small GPS but, unlike the Fi or the AirTag, they use LoRa as their method of communication [5]. LoRa allows them to bypass the high costs and energy utilization associated with LTE networks but it also constrains the locations that can be tracked. Your tracking device must be in the range of a LoRa gateway, which is up to 10km in rural areas and 3km in urban areas. Although only a limited number of regions have gateways, there are over 70,000 globally that cover most major cities. We chose to use LoRa because of its wide coverage, low power consumption, reliability, and cost efficiency.

III. System Architecture

The system architecture of the dog tracking system is illustrated in Figure 1, which describes the LoRa interface between the pet collar attachment and base-station hardware. It also describes the various communication protocols used between the different modules.

The Dawg Tracker contains the GPS, pedometer, speaker and micro-controller. It is the central hub of data acquisition pertinent to the activity and location of the dog. Meanwhile, the base station receives the acquired data and displays the information on a website that is hosted by the ESP32, a device with an integrated WiFi transceiver and micro-controller.

A. System Design

The Dawg Tracker system design in Phase I was driven by the goal to achieve low-power consumption while maintaining a reasonably small footprint. This led us to pursue highly integrated components as listed in Table 1 under the "PCB Part No." column. For the purpose of the prototype, larger but similar components were used as listed in Table 1 under the "Prototype Part No." column.

The M4 Feather Express contains the ATSAMD51 32-bit Cortex M4 core micro-controller and was selected based on its ability to automatically re-charge batteries while connected via USB. It also allows us to communicate with other peripherals in parallel with the option of using different communication protocols.

The alarm system consists of a piezoelectric speaker, which is the largest component in our Dawg Tracker. This component was difficult to source, since typical piezoelectric devices can require up to 70+ volts in order to excite the piezo. However,

TABLE II
Key System Components

Function	PCB Part No.	Prototype Part No.	Qty.
GPS	ORG1510-PM01	Ultimate GPS	1
Accelerometer	LSM6DSRTR	MMA8451	1
High Freq. Speaker	W-03A	W-03A	1
LoRa Modules	SX1280	RFM95W 900 MHz	2
Micro-Controller	M4 Feather	M4 Feather	1
Base Station	ESP32 Feather	ESP32 Feather	1
3.7V Batteries	ASR00003	ASR00003	2
Antenna	W3211 (915 MHz)	3 inch Wires (2) GPS Antenna (1)	-

we were able to find a speaker that only requires a 3.3V input in order to emit a 20 kHz sound wave. Thus, we sacrificed footprint size to simplify the system integration (eliminating the need for a high voltage power supply). Since analog pulses are required to excite the piezos, we connected the speaker to an analog output pin of the MCU.

The performance of our tracking system heavily relies on accurate GPS coordinates. Due to the significance of the GPS, specifications of the ORG1510-R02 [6] and Ultimate GPS [7] are summarized in Table 2.

TABLE III
GPS Specifications

Metric	ORG1510-R02	Adafruit Ultimate GPS
Dimensions	10x10x5.9mm	25.5x35x6.5mm
Interfaces	UART/SPI/I2C	UART
DC Supply	1.8 volts	3.0-5.5 volts
Accuracy	$<$1.5 meters	1.8 meters
Update Rate	1-10Hz	1-10Hz

The Origin-GPS is a highly integrated component that is capable of achieving high accuracy compared to other GPS modules. It also contains a built-in active antenna, which greatly reduced the footprint of our PCB design. When implementing the OriginGPS into our Dawg Tracker System, we added shunt capacitors to serve as EMI filters at the transmit and receive ports to attenuate undesired noise. We also included a voltage level translator to convert the 1.8V from the OriginGPS output to 3.3V as an input to the M4 Feather. Additional capacitors and voltage translators were not required for the Ultimate GPS that was used in Phase II.

In the PCB design, the accelerometer and SX1280 LoRa module communicate to the M4 feather through a multi-slave SPI protocol. The GPS coordinates are sent to the M4 feather using I2C protocols.

In the prototype, the Adafruit accelerometer interfaced with the M4 feather using I2C communication. The RFM95 Featherwing Board replaced the SX1280 LoRa, which used MOSI to send and receieve data. Lastly, the GPS coordinates were sent to the M4 feather through UART communication.

B. PCB Layout

The PCB of the Dawg Tracker was designed on a four layer board, which was manufactured by JLCPCB. In the stack-up,

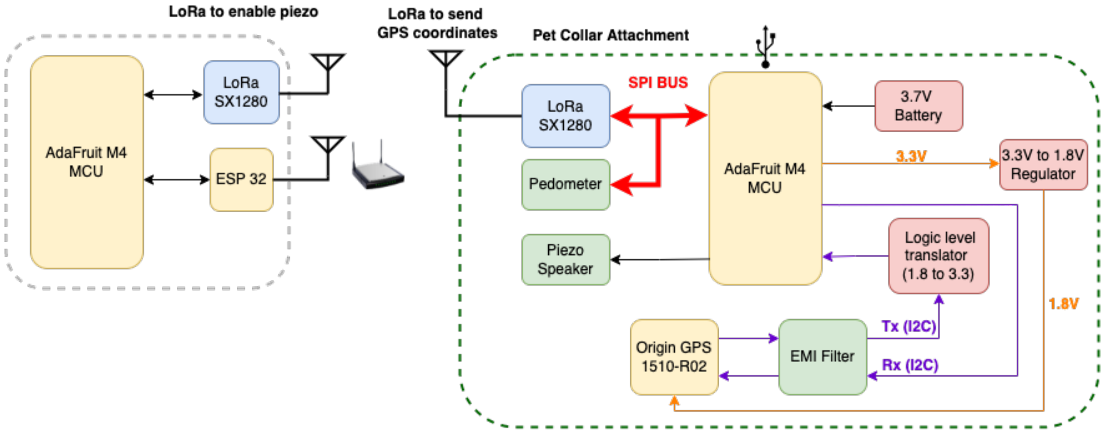

Fig. 1. Block Diagram of the Dog Tracking System. On the left, we have the base station which contains a Adafruit M4 Feather that controls both a LoRa module and an ESP32 module. On the right we have the dog tracker system which, again, has an Adafruit M4 feather controlling a GPS, LoRa Module, Pedometer, and Ultrasonic Piezo Speaker.

RF signals are routed on the top layer with the appropriate trace widths. The trace width is important for RF signals because it provides a matched line impedance for improved signal integrity. The trace width is dependent on the dieletric material of the PCB, which allows us to calculate the trace width accordingly. For our board, the only RF signal is from the SX1280 to the antenna. Since antennas are sensitive to its surroundings [8], we also added ground clearances to the LoRa antenna and the OrignGPS to minimize interference.

Following the top layer, the second layer was defined as the ground plane. This allowed us to directly add vias to make connections from the top layer to the ground layer when needed. The next layer was the dedicated power plane for the 3.3 volts to supply power to other modules on the board. The trace width for the power traces were wide to satisfy current requirements.

The bottom layer was used to route communication signals between the different modules. To obtain a visualization of the final PCB, a 3-D model was generated from KiCAD as shown in Figure 2.

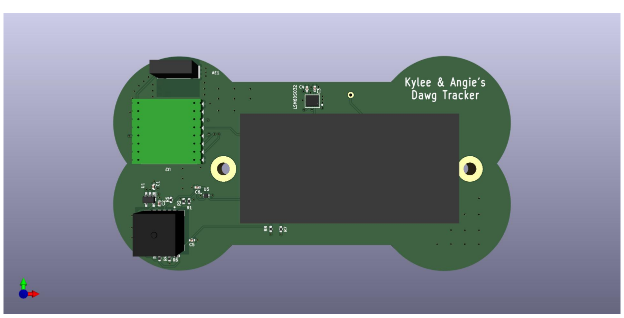

Fig. 2. PCB Design of the Dawg Tracker. The largest component of the PCB is the M4 feather. The drilled holes on each side of the M4 feather will be used to mount the piezo speaker (not shown) on the back of the PCB. The 3D model also shows ground clearances surrounding the antenna (top left) and GPS module (bottom left).

C. Software

The code is broken down into two different sections: the base station and the collar.

The base station consists of the M4 Feather, a Lora Feather Wing, and an ESP32. The first thing we do is configure both the LoRa and the WiFi modules. The base station accepts incoming messages and parses the messages for the current location, GPS read time, and the step count. It then calculates the distance that the dog is from the base station using the incoming longitude and latitude as shown in the code in Fig. 3 [9]. If the distance is within a user-defined safe range, we send back a "YES" to the dog collar, indicating that it should not sound the alarm. If the dog is outside the range, we send a "NO" which triggers the ultrasonic piezobuzzer.

```
int r = 6378137; // Earth's radius in meter
float dist_lat = rad(dog_lat - base_lat);
float dist_lon = rad(dog_lon - base_lon);
float a = sin(dist_lat/2)^2 + cos(rad(dog_lat))*
          cos(rad(base_lat))*sin(dist_lon/2)^2;
float c = 2* atan2(sqrt(a),sqrt(1-a));
float dist = r*c;
```

Fig. 3. Code for calculating the distance between the tracker and the base station

After we finish communicating with the collar, we use the information from the message to update our website as shown in Fig. 4. We created a simple HTML website which will automatically refresh every 20 seconds. We first print out the dogs distance and relative step count. Then we convert the GPS coordinates from decimal degrees to degrees minutes seconds. We use these coordinates and input them into the integrated Google Maps API to allow you to visualize your dogs exact location. We can provide this for free by only performing a maximum of 8,000 API requests per day. Since there are 86,400 seconds per day and the website is updated every 20 seconds, we perform only $\frac{86400}{20} = 4320$ requests, which is well under our daily maximum. The website is hosted locally and then we use Ngrok for creating a TCP tunnel. The TCP tunnel allows you to access the website from anywhere in the world.

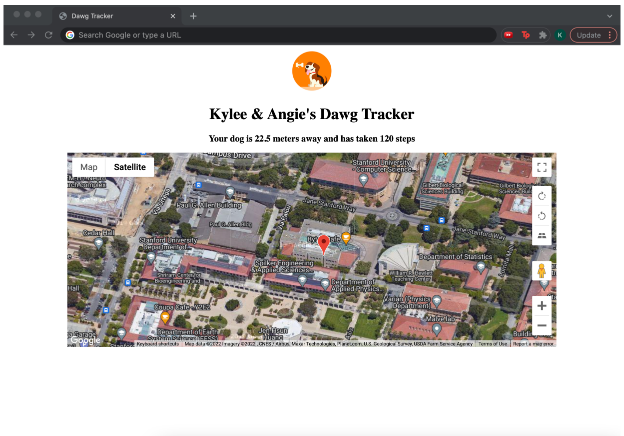

Fig. 4. Image of our website. The website uses the satellite version of the google maps API for better visualization of the surrounding location. It also shows the precise location of the Dawg Tracker using a google map marker (in red). The website is configured to refresh every 10 seconds in order to update the distance and step count data in the caption above the map.

On the dog collar, we have another LoRa Feather Wing, a GPS module, accelerometer, and speaker. In order to increment step counting, we leveraged the x, y, and z acceleration data from the accelerometer. The GPS was the most difficult to integrate. In the main loop, we read in each character from the GPS and, after two seconds, check that the GPS has a fix which we use to update the GPS information. The GPS reading and step count are sent to the base station with a comma delimiter. Then we check for a response from the base station. A "NO" indicates we should play the alarm by outputting a 20kHz wave to the speaker pin.

IV. Results

After assembling the hardware components and programming the micro-controllers, we were able to successfully transmit and receive GPS coordinates using LoRa. The Dawg Tracker System also recorded the approximate step count and distance from the base station.

When the Dawg Tracker was out of the defined bounds, the base station automatically enabled the piezoelectric speaker by sending a signal to the Dawg Tracker through LoRa. The frequency of the speaker was verified by an app called "Clear Wave" that is available from the apple app store. The speaker also made a slight clicking sound when activated, which confirmed that the Dawg Tracker emitted an alarm as we expected.

Meanwhile, updates related to the step count, distance from the base station, along with GPS coordinates of the dog tracker were updated in real time on the GPS website. The Dawg Tracker and base station were also battery powered, which allowed the base station and DawgTracker to be portable. Figure 5 and figure 6 show the final prototype of the Dawg Tracker and Base Station respectively.

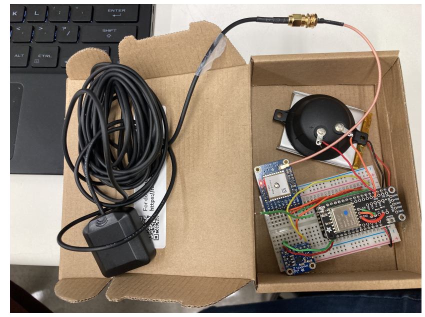

Fig. 5. Image of Dawg Tracker Prototype. On the left, the bundle of wires is the external GPS antenna. On the top right, the large circular component on the top is the piezo speaker which will also be used in the final PCB design. The breadboard on the bottom right contains the accelerometer, GPS, and LoRa Module. The 3.7 volt battery that powers the Dawg Tracker is shown underneath the piezo speaker.

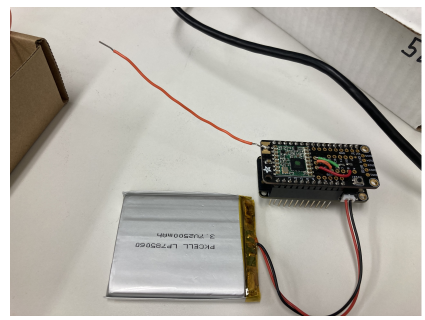

Fig. 6. Image of Base Station. This image shows the RFM radio stacked on top of the ESP32 Feather to establish pin connections. A wire is soldered to the RFM radio that is used as the antenna. The base station also uses a 3.7 volt battery for power.

V. Future Work

Going forward, we have a considerable amount of work to do in order to obtain a commercially viable product. As mentioned earlier, we were only able create a simple prototype of our larger system due to manufacturing and delivery constraints.

Our first task is to bring up our SX1280 boards, which consists of a more sophisticated LoRa IC. The SX1280 has a Ranging feature allows us to precisely measure the distance from our dog to the the base station within a 3-10 km span [10]. This is significant because it would allow us to bypass the GPS completely, relying only on the LoRa for location. If we were to remove the GPS, we would save a significant amount of money and battery life, as well as differentiate ourselves from other trackers on the market. On the other hand, the SX1280 can only supply a scalar distance so the user would not be able to get positional or directional information. That fact alone makes it unlikely we would ever discard the GPS module.

After we get the SX1280s working, we will finish bringing up the rest of our PCB board. We will need to test each additional part that we integrated into the board including the pedometer, GPS, and speaker. The code for our board should be significantly different from the code for our prototype. For example, the GPS we used in our prototype communicated over SPI and has built in Adafruit libraries. Our new OriginGPS will communicate over multi-master SPI and does not have a dedicated Arduino library. Once we've verified each component, we will test the system as a whole to identify its functional range.

VI. Conclusion

Based on the results of our prototype, we proved that LoRa communication is an effective solution for a wireless dog tracking system. Our functional system was prototyped on a breadboard, which can be replaced by a 4 inch wide PCB board that was designed as an outcome of this project. With the challenges pet-owners face, we are motivated to continue advancing the Dawg Tracker System into a more scalable, reliable and unique design.

Acknowledgment

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