# LoRa-based Localization System for Emergency Services in GPS-less Environments

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# LoRa-based Localization System for Emergency Services in GPS-less Environments

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***Abstract*—The introduction of Global Positioning Systems (GPS) to the public has provided millions of people with navigation and positioning services around the globe. However, it is known that no matter the improvements to accuracy, fundamentally, GPS cannot provide location information in extreme environments, such as underwater and underground. Hence, there is a growing need for alternative technologies and methodologies of providing localization in such extreme or GPS-less environments. This paper introduces a low-power and low-cost substitute founded on Long Range (LoRa) to realize similar localization capabilities, based on the Received Signal Strength Indicator (RSSI) techniques. LoRa transceivers support swift deployment in GPS-less emergency scenarios, providing emergency teams with critical location and sensing data. According to outdoor experimental results, LoRa is a promising solution for wireless localization systems at GPS-less environments.**

## I. Introduction

Global Positioning System (GPS) services have a strong foundation in our navigation and localization needs. Unfortunately, there exist environments where GPS is no longer suitable. These GPS-less environments often include mountain regions, where Line-of-Sight (LOS) and physical obstructions inhibit signal reception with satellites. Other environments like underground or underwater also pose similar issues that result in GPS no longer being able to provide accurate location information, if at all. Long Range (LoRa) is a promising alternative for wireless localization systems.

LoRa is a low power wireless technology that operates at various frequencies depending on the region, such as 868 MHz for Europe and 915 MHz for North America [1]. Its sub-gigahertz transmissions allow for long-range communications up to 10km in many environments [2]. LoRa technology can be exploited for localization purposes, similar to other technologies like Wi-Fi and Bluetooth [3]. However, its transmission range is over 1000 times greater than Bluetooth 4.0 or Wi-Fi, making it more suitable for large outdoor regions. LoRa still employs the same localization principals as the alternatives, where RSSI techniques can be used in conjunction with trilateration in order to determine an estimated position [3]. A minimum of three LoRa receiving anchor nodes and one LoRa transmitting dynamic node are required to implement the localization system.

Often, this scheme is used for indoor localization systems, especially within the framework of the Internet of Things (IoT), such as in [4] and [5], where an improved RSSI-trilateration positioning algorithm is proposed. In remote or extreme environments, where nodes must be placed where there is no constant power infrastructure, low power RSSI localization systems, are a high priority. In [6], it is proposed a power management technique for outdoor localization that yields 6.7 uA in sleep mode.

The low power and long-range characteristics make LoRa a great suitor for quick deployment in especially remote, extreme, or even dangerous environments. These environments may pose scenarios in which added sensing presents additional benefits. For example, a localization system for tracking the servicemen/women fighting a forest fire may also record and transmit the localized $CO_2$ and temperature values alongside their estimated location.

In this paper, the proposed localization model utilizes Dragino shields to implement LoRa wireless communication technology. These devices are controlled and programmed via Arduino micro-controllers, which also provide vast support for added sensing mechanisms. Hence, this paper contributes to the furthered development and exploration of localization accuracy and power consumption as it relates to the feasibility of rapidly deployable LoRa-based localization systems for emergency services in GPS-less environments. Experiments were conducted during a cold winter day at an outdoor environment with promising experimental results.

The rest of the paper is organized as follows. Section II discusses the related research pertaining to LoRa-based localization as well as alternative implementations. Section III gives a detailed description of the proposed system architecture. This includes the overall topology, hardware, communication mechanisms, and software. In Section IV, the path-loss model, power measurements, and localization accuracy experiments are described. The results are discussed in Section V and the delineation of the results with respect to a model built using GPS in Section VI. Finally, the conclusion is in Section VII.

## II. Related Work

There is a lot of growth in research for indoor and outdoor localization systems that act as a substitute for GPS. GPS-less localization, particularly realized with LoRa has been explored and its feasibility proved in [7]. In [8], the authors present a more robust LoRa localization system that detects and removes outlier nodes, as well as incorporates a density cluster analysis to improve the RSSI-based localization accuracy. The work presented in [9], experiment with the combination of LoRa, solar harvesting, and Real-Time Kinematic (RTK) technology in order to devise a self-sustaining outdoor localization system. Accuracy results below 1m are reported, however, this accuracy lies only by being within 700 m of an anchor node. A peak power consumption of 300 mW was also reported when RTK and LoRa radio are used simultaneously. In [10], it gives detailed insight into the characteristics of LoRa communication, specifically with respect to signal coverage, signal distribution, device density, and device motion. It was shown that RSSI measurement discrepancies between devices (of the same model) are measurable and significant. In static positions, RSSI values were also shown to change over time, although no attempt at linking environmental changes with time-varying measurements was made. Furthermore, the RSSI values were shown to differ vastly between indoor and outdoor environments, as would be expected. RSSI measurements are known to be dependent on the environment, as discussed in [3].

There are a number of ways in which to improve on the raw RSSI measurements obtained in a wireless localization system. Assuming the tuning parameters regarding transmission rate and transmission power of a node have been properly defined for the environment in which the node is deployed, state-estimation filters like the Kalman and Gaussian filter are often used to improve measurement accuracy, as detailed in [11] and [12]. Alternatively, machine learning techniques like k-NN, as shown in [13], can also be used to better estimate the true RSSI value, in order to make up for the dynamics and noise of an environment.

Despite the growing trend in localization research, there is still a need for further development and improvements for real-world localization systems, particularly in swift deployment, low power consumption, and high scalability for extreme environment applications. Hence, this paper attempts to fill in the gaps with this respect.

## III. System Architecture

This section provides details on the required communication technology and hardware to implement and test the proposed LoRa localization system.

### A. Communication Technology

LoRa itself is a license-free wireless communications technology that was developed by Cycleo in 2009 [14]. It was designed specifically for low power consumption and long-range transmissions. It operates in sub-gigahertz bands, such as 868 MHz for Europe and 915 MHz for North America.

### B. Hardware

In order to implement the LoRa technology, the proposed system uses the Dragino LoRa v1.3 Shield devices [15], shown in Fig. 1, which are designed to be programmed and integrated directly with an Arduino Uno micro-controller [16]. The LoRa shield also has an integrated GPS module, which will be used for comparison. Both devices have a very small form factor, making it ideal for easy deployment and concealment from physical tampering.

Measuring power consumption is another aspect of characterizing the localization system. In order to do this a Monsoon

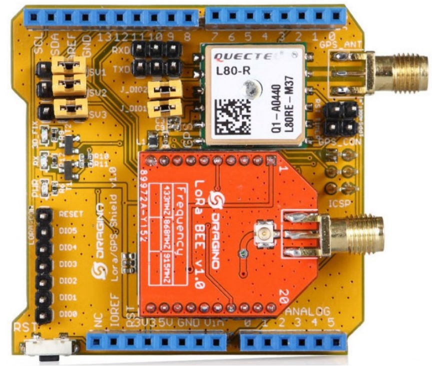


Fig. 1: Dragino shield v1.3 [17].


Fig. 2: Monsoon power monitor [18].

power monitor, shown in Fig. 2 is used [18]. The Monsoon is capable of monitoring multiple power characteristics, including average power and average current at a sample rate of 1kHz.

## IV. Experimental Procedure

This section describes the two experiments conducted in order to obtain localization accuracy and power consumption characteristics of Dragino LoRa shield devices, and compares them to its GPS alternative.

### A. Positioning Accuracy

Before the positioning of a node using trilateration can be obtained, a path-loss model must first be developed. A path-loss model is a signal propagation model that represents the signal strength at increasing distances. For the purposes of the following trilateration experiments, a path-loss model of 8 points is developed at distances of 5, 10, 20, 40, 60, 80, 100, and 150 m. For all conducted experiments, the LoRa shields will be configured to transmit 2 times per second at a transmission power of 20 dBm. The transmission power of 20 dBm is chosen due to the nature of the smaller 100 m geo-fence topology. Using the RSSI values obtained at these points, a best curve fit function can be developed in order to determine the approximate distance between the transmitting and receiving node. The path-loss formula is as follows:

$$RSSI = -10 * n * log10(x) + C \quad (1)$$

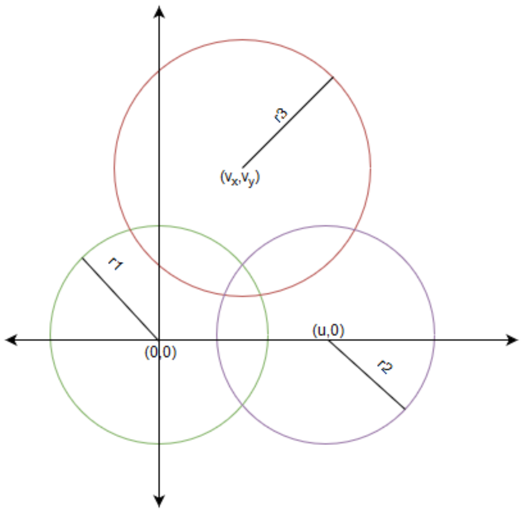


Fig. 3: Trilateration setup overview.

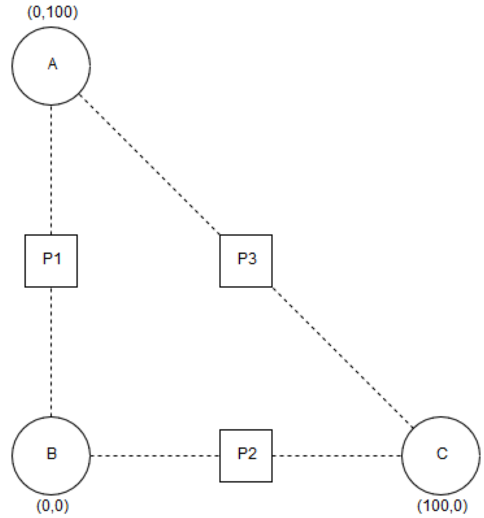


Fig. 4: Experimental layout.

Fig. 5: Experimental environment.

where $n$ is the propagation loss factor due to the wireless medium, $x$ is the distance between the nodes, and $C$ is a constant loss factor that accounts for noise in the system.

The positioning of the proposed system is realized only in 2D space, where three dimensions would require a more complex model. Once the path-loss model of the environment is obtained, the collected RSSI values are averaged and then translated into distance using the following equation:

$$d = 10^{\frac{C-RSSI}{10n}} \tag{2}$$

Once all of the distance estimates to all three anchor beacons are determined, the general form of the trilateration algorithm is utilized in order to solve for the $(x, y)$ position. The general setup of trilateration is depicted in Fig. 3. The final solution is the overlap of all the anchor nodes which can be fully realized by calculating the three equations 3, 4, and 5, similar to [3]:

$$r_1^2 = x^2 + y^2 \tag{3}$$

$$r_2^2 = (x-u)^2 + y^2 \tag{4}$$

$$r_3^2 = (x-v_x)^2 + (y-v_y)^2 \tag{5}$$

Using reduction, the solution to $x$ and $y$ can be found which satisfies all three equations, thus resulting in the final position. Rearranging, the final position $(x, y)$ is calculated as follows:

$$x = \frac{r_1^2 - r_2^2 + u^2}{2u} \tag{6}$$

$$y = \frac{r_1^2 - r_3^2 + v_x^2 + v_y^2}{2v_y} - \frac{v_x}{v_y} * x \tag{7}$$

The experiment were conducted within a 100 m, square geofence under three pre-determined positions (0 m, 50 m), (50 m, 0 m), (50 m, 50 m), where the RSSI from all three anchor beacons will be measured over a period of 3 minutes at each location. The general layout of this experiment can be seen in Fig. 4.

In order to quantify the accuracy, the Mean Squared Error (MSE) of each position is calculated as follows:

$$Error = \sqrt{(x_{calc}^2 - x_{expected}^2) + (y_{calc}^2 - y_{expected}^2)} \tag{8}$$

### B. Experimental Environment

With respect to the localization experiments, the development of the path-loss model and trilateration experiments were conducted outdoors within the bounds of a small soccer complex ($200m \times 120m$) at the University of Guelph, shown in Fig. 5. The soccer field complex is relatively open, which is good for a baseline positioning experiment based on RSSI. It is important to note that the experiments were conducted on a cold winter day ($\approx -50°C$ and $\approx 67\%$ humidity). It is known that temperature and humidity have an effect on the RSSI [19], inversely proportional to temperature, but proportional to the humidity.

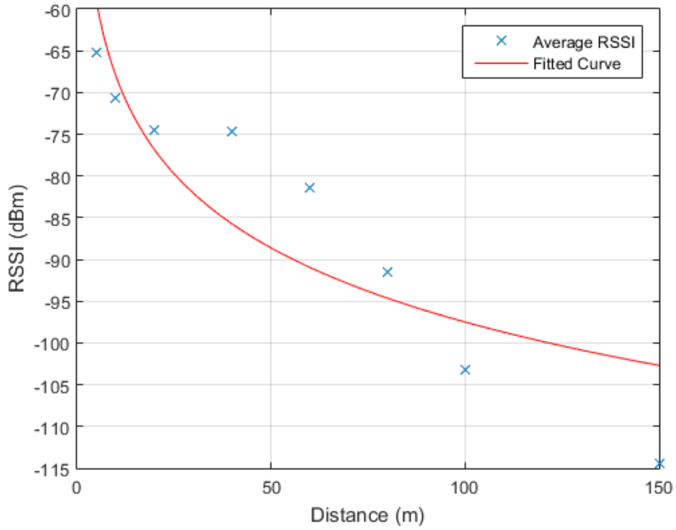


Fig. 6: Path-loss with best curve fit.

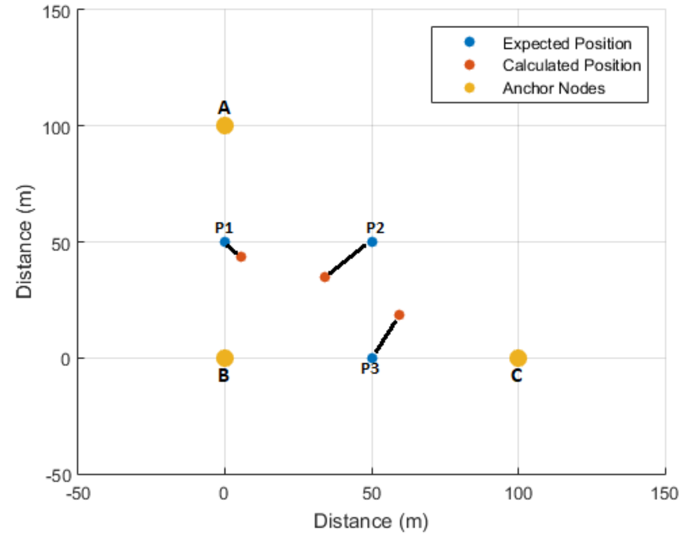


Fig. 7: Trilateration results plot.

| Real Position | | Estimated Position | | **Mean Square Error (m)** |
|---|---|---|---|---|
| x | y | x | y | |
| 0 | 50 | 5.47 | 43.30 | 8.65 |
| 50 | 0 | 59.41 | 18.67 | 20.91 |
| 50 | 50 | 34.27 | 34.76 | 21.90 |

TABLE I: Positioning error.

### *C. Power Consumption*

In order to explore the power consumption of the Dragino LoRa shield devices, the Monsoon power monitoring tool was used. Each experiment measured the average power consumption over a span of 5 minutes. As aforementioned, there are two critical configuration parameters that affect the power consumption, and consequently the lifespan, of a completely wireless transmitting node. These are the transmission interval and the transmission power. The power consumption of the LoRa nodes is tested in its receiving and transmitting states. Furthermore, in its transmitting state, the LoRa nodes are tested in six total configurations, three transmission power levels, 0dBm, 10dBm, and 20dBm, at two transmission intervals, 1Hz and 2Hz, in order to develop a more detailed understanding of the power relationship between the configuration parameters and the overall power consumption of the node. All of these power measurements are plotted and compared to that of the GPS module, also integrated into the Dragino shield. Note that all GPS parameters are constant and cannot be modified/redefined.

## V. Results

### *A. Positioning Accuracy*

Figure 6 depicts the result of the developed path-loss model. Via the best curve fit algorithm, fit to Eq. (1), the propagation loss factor $n$ was found to be 1.917 and the system noise factor (in dBm) $C$ is -49.59, with 95% confidence.

Figure 7 depicts the layout of the experiment with the actual versus the expected positions of the LoRa node. The positions and their relative mean squared error of all three points can be seen in Table I. The results are reasonable for the model, achieving a minimum mean squared error of 8.65 meters, and may benefit from additional filtering algorithms. Improvements may also be realized with a better path-loss model.

The poor accuracy may be attributed to some interference due to snowfall, as well as some obstruction in the LOS due to metal fencing. In more complex environments, the error is likely to magnify. Hence, the need for additional filtering. Furthermore, alternative configurations may have provided better results, such as increasing the transmission power of the anchor nodes. If the obtained results and error were consistent within a larger region, these results may still provide useful location information, giving a good sense of the asset or person being tracked. In order to better account for environments with poor LOS, a path-loss model should be developed with similar LOS to the final implemented model. Moreover, this confirms that in order to achieve accurate localization, an accurate path-loss model of the particular environment must be developed beforehand.

### *B. Power Consumption*

Figure 8 depicts the power consumption of the Dragino LoRa shield versus the GPS module also integrated into the Dragino shield. The aim of this comparison is to portray the power cost of a node setup to be a receiver. In the case of GPS, you only need the GPS receiver, while in the case of LoRa, three transmitter beacons and one receiver beacon is required to implement trilateration. It can be seen that GPS requires far more power than the equivalent LoRa-based receiver node, 177 mW compared to 110 mW respectively.

Figure 9 shows the power consumption of the LoRa node in six configurations. The corresponding average current values can be seen in Table II. These are used to calculate the expected lifetime of the node. The configurations consist of

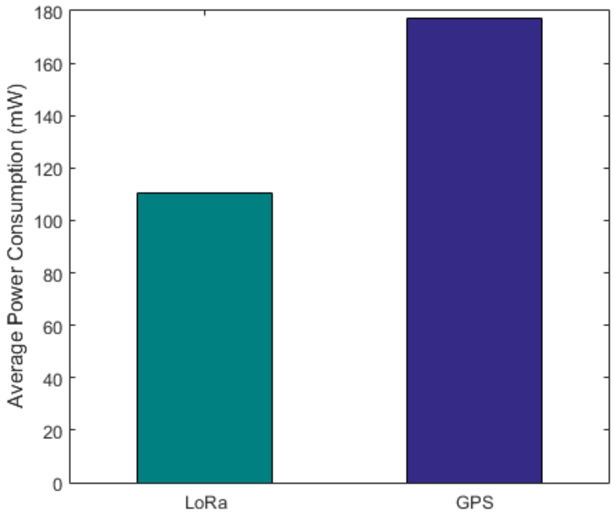


Fig. 8: Power consumption at receiver node.

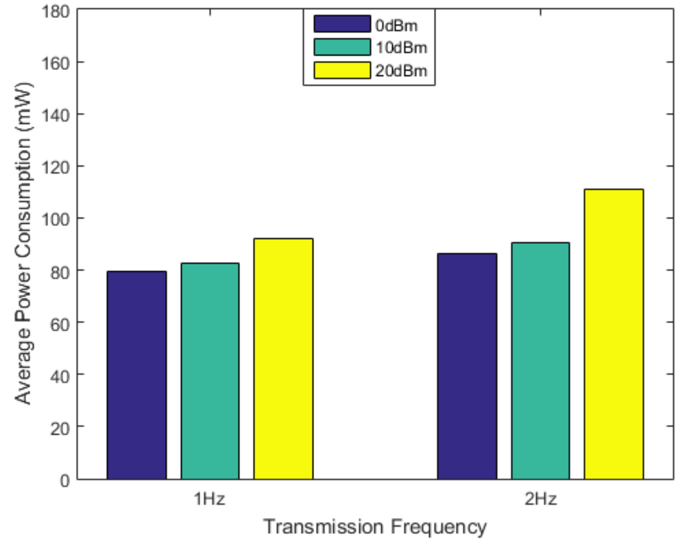


Fig. 9: Power consumption at transmitter node.

three transmission power levels (0 dBm, 10 dBm, and 20 dBm), each at two transmission frequencies/intervals (1 Hz and 2 Hz). Higher transmission power translates to greater transmission distance and has some relation to the achievable accuracy. Faster transmission intervals correspond to better real-time localization capabilities, and can even help accuracy, especially if state-estimation filters are integrated into the localization system, similar to [11]. As expected, power consumption is directly proportional to the transmission power and transmission rate. The LoRa node achieves a minimum power consumption of 80 mW at (0dBm, 1Hz) and maximum power consumption of 110 mW at (20 dBm, 2 Hz). For reference, the receiver node had a power consumption and average current of 177mW and 38.9mA respectively.

In order to give a fair power consumption comparison with GPS, the power consumption of the entire LoRa system needs to be taken into account. So for every GPS receiver, three LoRa transmitters, and one LoRa receiver is required. Thus, the minimum average power consumption of the proposed LoRa localization system, assuming a transmission power of 0 dBm and a transmission rate of 1 Hz is:

$$total_{pwr} = (3 * 80mW) + 110mW = 350mW \tag{9}$$

However, it is important to take into account that with added dynamic nodes that participate within a three anchor LoRa localization system, the power benefits of LoRa will soon outweigh GPS. Figure 10 depicts the point at which the LoRa system outperforms GPS in terms of power consumption. After only four devices, the lower power characteristics of the entire LoRa system provide better power consumption results than the GPS alternative.

## VI. Discussion

The results of the trilateration positioning experiment were as expected for true RSSI-based localization in a dynamic environment, especially without any additional state-estimation filtering. In extreme environments and emergency situations, the LoRa localization system can still provide a general sense of location as well as be adapted to provide location-specific sensory data as well, which is an important advantage that LoRa provides over GPS.

There may be environments that still possess the capacity to support GPS localization, but the signals are hard to obtain due to physical interference and issues with LOS, like crevasses and valleys between mountain ranges. Here, LoRa localization may be able to make restitution for lack of LOS and provide

| | Configuration | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | **1** | **2** | **3** | **4** | **5** | **6** |
| Tx Power (dBm) | 0 | 0 | 10 | 10 | 20 | 20 |
| Tx Interval (Hz) | 1 | 2 | 1 | 2 | 1 | 2 |
| Avg Current (mA) | 17.55 | 19.04 | 18.99 | 20.00 | 20.36 | 24.47 |

TABLE II: Average current consumption of LoRa transmitter.

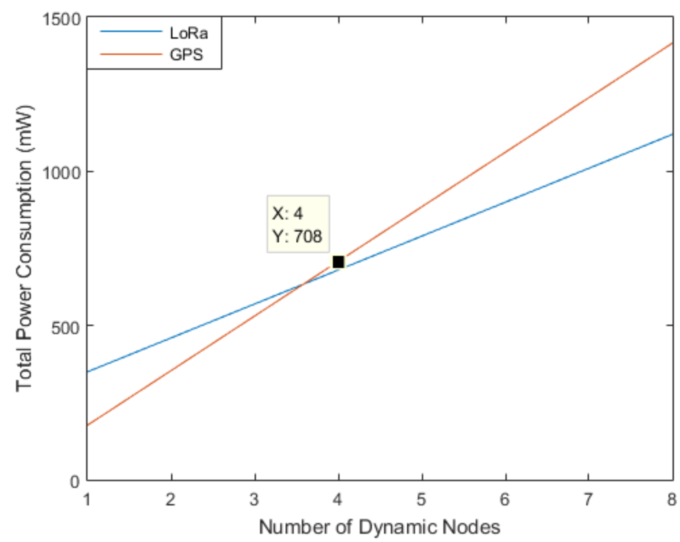


Fig. 10: Total power cost of two technologies.

better results in terms of quick location estimation.

A critical analysis of the power consumption is relating the consumption to the expected battery-life of the node. Battery life can be calculated as follows:

$$Lifetime(hours) = \frac{BatteryCapacity(mAh)}{LoadCurrent(mA)} * 0.70 \quad (10)$$

where $0.7$ is a conservative gain factor used to account for external impacts like humidity and temperature on battery life. Hence, a single dynamic LoRa transmitting node could last approximately 200 hours with a 5000 mAh battery bank as per configuration 1 in Table II, and the receiving node 90 hours, assuming a consistent current load of 25mA as per the power consumption experiments. For testing purposes, three 2500 mAh AA-batteries were used to power each node, allowing them to last up to three days without replacement, in their tested configuration (20dBm, 2Hz).

Upon improvement of the positioning accuracy, the LoRa shields offer great energy efficiency and make them an ideal choice for quick transmitters that can continuously operate for over a week on a small battery bank. This is very useful in ongoing emergency situations, such as forest fires or search and rescue missions.

## VII. Conclusion

This paper characterized and implemented an outdoor, LoRa-based, localization system that can be very quickly deployed. The initial positioning results vary, with the positioning error ranging from $\approx 9-20$ meters. Future work will focus on improving the LoRa positioning accuracy with added state-estimation filters as well as more advanced machine learning techniques. The clear benefit of LoRa technology is the low power consumption that it offers, as well as the simple integration of localized environmental sensory data. The Dragino LoRa transmitters can be quickly deployed and setup, similar to the portrayed experiments, in a matter of minutes. These attributes make LoRa technology a good contender for localization systems in GPS-less environments.

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