Integrated Multi-standard system based on LR1110 for geolocation applications

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***Abstract*—This article presents a multi-standard system for geolocation applications. The multi-standard Semtech LR1110 components are integrated into a multiple antenna platform. For indoor scenarios, the proposed terminal can be positioned by WiFi Passive scanning technique. For outdoor methods, GNSS positioning is used. Moreover, this system supports LoRa communication to send the data to the server for different tracking or positioning applications. The board is packaged on an IP65 enclosure with an overall dimension of 90mm x 90mm x 40mm. With the average power consumption down to 26.6uA, this proposal is suitable for the low-power wide-area network (LPWAN).**

***Index Terms*—Transmit, receive, sleep, LoRa, GNSS, WiFi-Scan**

I. Introduction

Nowadays, with the development of information technology in general and IoT(Internet of Things) in particular, the demand for tracking has also increased significantly, typically locating objects, people, or wild animals, pets. Therefore, several positioning technologies were designed to serve people helpful [1]–[4]. Outdoor positioning and indoor positioning are two main areas of positioning applications.

Regarding applications for outdoor positioning, the [5] study on human positioning using satellites combined with Kalman data filters to reduces the average error. Moreover, In [6] the author proposes another technique based on the Kalman filter that can improve accuracy achieve 2m(reduces 81%) compared to the measurement accuracy. According to research, [7], GNSS mentioned this method's weakness because it cannot use if the device is placed in an indoor environment or is shielded from the signal to the satellite. The Ground-based High-precision Local Positioning System (GH-LPS) in study [8] provides high performance for both indoor and outdoor positioning. Still, this method is challenging to implement because of its high cost. Besides, a few studies have mentioned the Time Difference of Arrival (TDOA) technique based on LoRa communication technology. This technique also supports positioning in the outdoor environment, but the obtained error is relatively high up to 200m [9], [10].

In addition to the outdoor context, indoor positioning is also concerned about using technology BLE, LoRa, ZigBee... Wireless Local Area Network (WLAN), primarily based on the 802.11 standards, is popularized worldwide, thanks to the information available in the end node device. Besides, the WiFi Scanning technique mention in [11], [12] is proposing that using the RSS measurements but without having to access the access point (AP). Still, with this method, it depends on the location of the registered access point so that the error may be different can reach hundreds of meters. To improve the accuracy of this method, in [13] has integrated a neural network model to determine the floor and building. Additionally, many studies have been performed to reduce the error. Specialty, the proposal in [14] has been committed to reduce the error to less than 4m.

Besides, multi-environment positioning devices have also been studied and realized. In [15], the authors combine GPS and RFID to be able to work indoors and outdoors. Additionally, A-GPS and WiFi studied in [16] are used in mobile devices with an error of 8m and 74m, respectively. GNSS-UWB is also a solution that can be located devices indoors and outdoors [17]. This proposal has shown the advantage below 0.5m of the indoor error. However, UWB has not been widely deployed because the hardware cost of the system is relatively high. In [18], the authors had studied navigation devices using GPS and WiFi. The system power consumption can be reduced to a maximum of 0.17mA/s in a sleep state. However, this article does not mention the accuracy.

In addition to positioning, transmitting this information to the station is also a challenge, especially for small devices, with limited power on device. With the advantage of low energy consumption, ZigBee could be a solution for transmitting location packets in the article [19]. In [20]–[22], the combination of GPS and GPRS helps data collected from the device to be easily transmitted to the processing center. Similarly, [23] GPS and SIM900 module can use 2 Alkaline AA LR6 batteries that can operate continuously for more than two months.

This paper presents a low-power, multi-standard system for indoor and outdoor positioning applications based on IC LR1110. In the following section, we will describe the hardware, communication with the server, power consumption, and accuracy through experiments.

II. Hardware Design

The proposed system consists of 2 main parts: the LR1110 circuit and the multiple antenna platform. The LR1110 circuit is soldered onto the antenna board so that the outputs match the antenna ports.

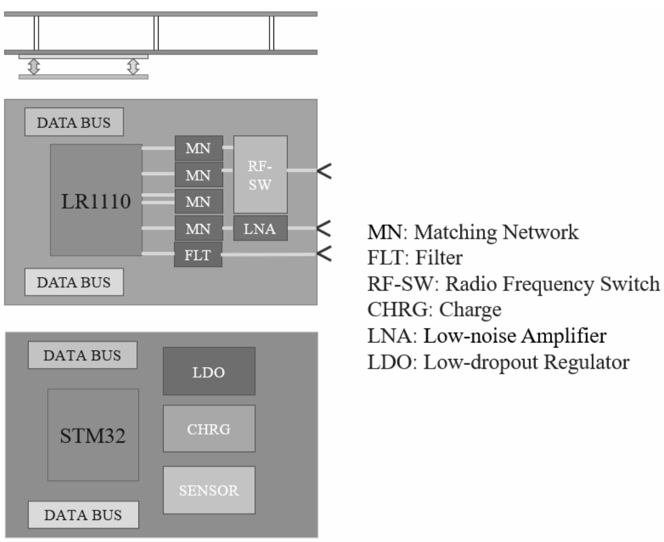


Fig. 1: Hardware block design system

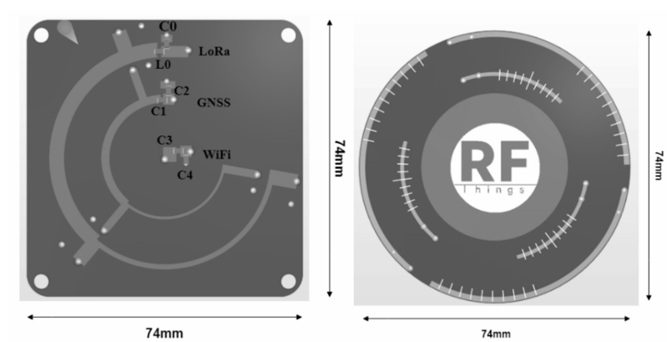
A. LR1110 Circuit Design

LR1110 is an ultra low power IC from Semtech that supports several standards such as LoRa communication, multi-constellation GNSS scanner, and passive WiFi AP MAC address scanner. By adding some circuits of power management, microcontroller, sensors, and radiofrequency unit. In our proposal, the whole hardware is divided into two parts, as Figure 1, the LR1110 board and the control/sensor unit board. For the LR1110 board, the RF elements such as the microstrip line, the filter, the LNA circuit, and the matching network are strictly designed to follow the manufacturer's guidelines. The RF output is located at the position corresponding to the feeding point of the antenna platform. Regarding circuit control, we use ST company STM32L476RG microcontroller with 32-bit Arm® Cortex®-M4 RISC core operating with a frequency of up to 80 MHz in addition to 1 Mbyte Flash memory. This microcontroller can be used for high processing performance applications while maintaining low-power consumption. In addition, the circuit is also integrated with several features such as sensors, power management circuit, LDO. The control board communicates with the LR1110 board using SPI protocol over the data bus ports, so the two circuits are designed to be stacked. Furthermore, dividing the LR1110 circuit into more minor elements makes debugging and integrating other features more accessible.

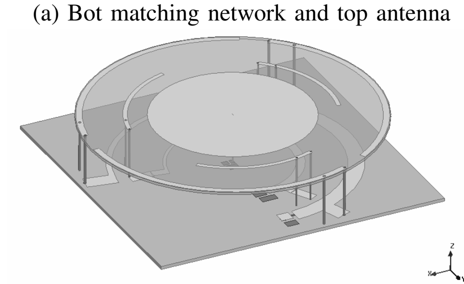
B. Antenna Design

Besides the electronic circuits, the antenna plays an important role. It not only determines the RF communication quality but also affects the overall size of the actual hardware. Additionally, the antenna must be designed to be easily integrated into the carrying enclosure to ensure that the device can still function properly if the device moves. Furthermore, since many communication technologies are integrated into the LR1110 IC, an integrated antenna system is required for different technologies. For the positioning task, the antenna system supports the GNSS frequency band and WiFi 2.4GHz frequency band. Moreover, the antenna has also worked at 900Mhz for the LoRa frequency band. Another problem is that the antenna ports must match the output ports of the LR1110 board to connect directly without a cable, so the placement of antennas must also be considered in the design process.

The bottom circuit of the antenna contains the matching network, including RLC components that can adjust antenna parameters such as operating frequency. The optimal value of the components is defined thanks to the simulation process by software and returning during measurement. Figure 2 shows antenna design and matching network circuit.



(a) Bot matching network and top antenna



(b) Isometric view

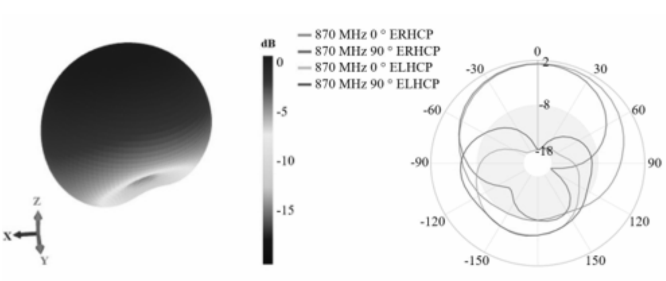
Fig. 2: Antenna Design

The component values after actual measurement are shown in the following table:

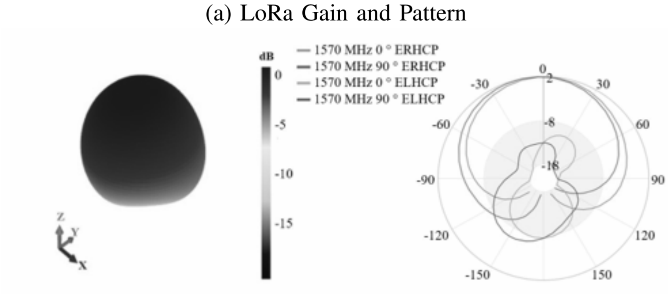
TABLE I: Variable of Component matching-network

Component	Value
L0	1.8 nH
C0	4.7 pF
C1	5.6 pF
C2	NC
C3	0.2 pF
C4	NC

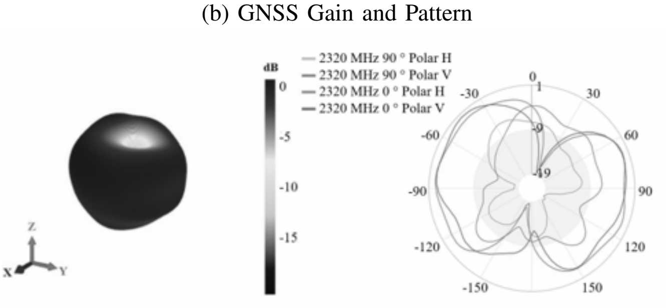
The radiation of the antenna is measured with a Satimo star lab meter giving the results as shown in Figure 3. We can see that GNSS and LoRa antennas have directional radiation patterns suitable for long-range communication. Besides, a WiFi antenna has isotropic radiation, has the strength in scanning surrounding WLAN devices.



(a) LoRa Gain and Pattern



(b) GNSS Gain and Pattern



(c) WiFi 2.4GHz Gain and Pattern

Fig. 3: Antenna radiation results

C. Collect And Transmit Data To The Server

At begin, the device must be connected to the server through the join request process. First, a join packet containing information about deviceEUI, joinEUI, and PIN is sent to the Semtech network server. Here the deviceEUI of the LR1110 will be checked with the LoRa Cloud database, and then the server will send the results back to the device and make a connection if the device is accepted.

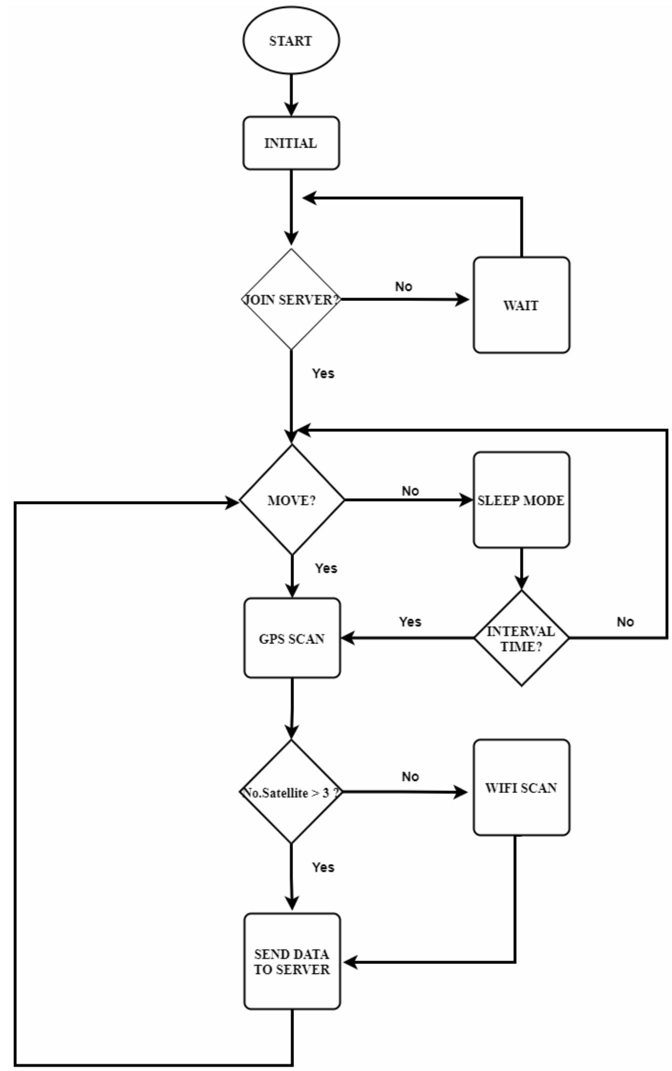


Fig. 4: Flow chart of collect and send data to server

For outdoor positioning: LR1110 supports gathering information from GPS and Beidou satellites flying around the earth via NAV message, then sending it to LoRa Cloud to calculate the current position. If it receives the required number of satellites, the device will skip the indoor positioning task by WiFi Scan. This method not only helps to determine the positioning environment of the device to integrate navigation sensors in several other applications easily [24] but also helps to reduce energy consumption and downtime required during a data collection cycle collect and transmit data to the server.

For indoor positioning: This process following collecting data by GNSS and the number of satellites is not enough to calculate the device's position. The LR1110 scans the WiFi MAC addresses to determine the RSSI-based location from the devices to each access point. The LR1110 can detect available b/g/n WiFi access points in the vicinity of the device and extract the MAC address allowing geolocation of the device.

The goal is to obtain at least 2 MAC addresses, which can be used to locate the device. They are next sent to the LoRa Cloud for location lookup.

An accelerometer sensor is added to the device to detect movement. The microcontroller would send a command to allow the whole equipment to turn on sleep mode if the accelerometer saw it has not moved. The condition that it detects the device has driven, it wakes up the LR1110 and resumes a new cycle of data collection and sending it to the server. If the accelerometer is not configured, the microcontroller only wakes up the LR1110 after certain user-configurable intervals. That is a solution that can help reduce power consumption if not needing continuous data about the server (real-time).

After the data collection phase, the information is packaged and sent to the server using the LoRaWAN protocol through the LoRa gateway, and the model network is shown in Figure 5. From the collected data, the server will analyze and give information about the location of the device. Using the provided APIs, users can quickly get the data after it has been processed. Thingsboard is the solution that the author team operates as a client-side to display the location visually on the map; this is a convenient and straightforward method. Besides, for the collected data, many other back-end applications can be developed.

LoRa Cloud geolocation is a service from Semtech that provides APIs that make locating devices easier. The Semtech Network Server connects to the LoRa Cloud service to extract the information from the device includes location, battery, RSSI, and device ID.

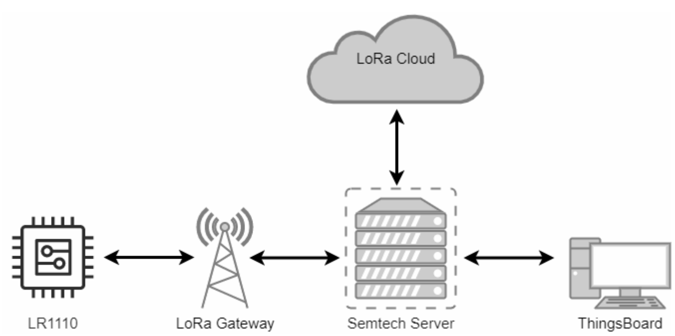
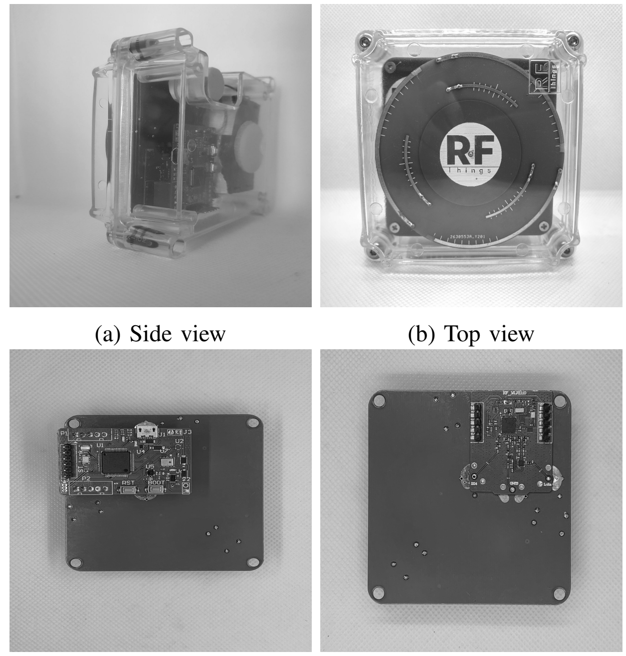


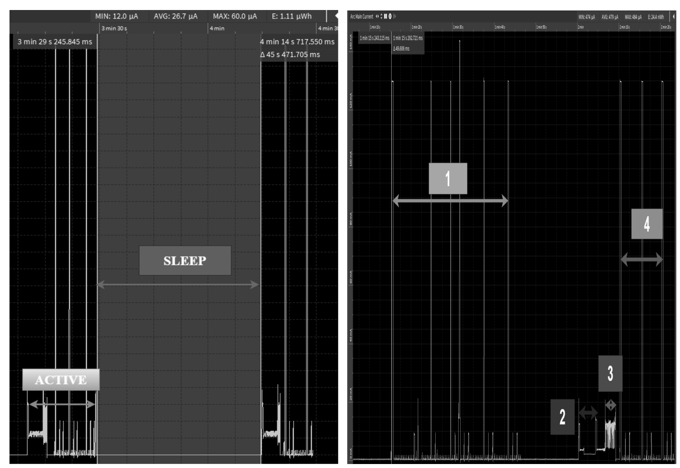
Fig. 5: Network model



(a) Side view (b) Top view

(c) Bottom view with control board (d) Bottom view with LR1110 board

Fig. 6: Prototype device



(a) Sleep and active (b) Active state

Fig. 7: Power consumption

III. Results and Discussion

Figure 6 showed the device is packaged in an IP65 standard box with dimensions of 90x90x40mm. The device is tested for power consumption and accuracy of positioning to evaluated performance.

A. System Power Consumption

The energy consumed during one cycle of equipment operation is measured by OTII, as Figure 7 follows:

- (1) The device will first send "Join Request" to the server with an energy level of 130mA after being received by the "Accept" server, and the device will exchange some information to synchronize. This process only occurs the first time since active and keeps the connection to the server without rejoining. The average current consumption is 5.5mA for this whole process in 31s.
- (2) After time synchronization, the device will conduct a GNSS scan with an average energy of 3.96mA in 4.3s (depending on the number of satellites).
- (3) WiFi scanning will follow immediately if the number of GNSS satellites does not meet the requirements and consumes an average of 8.51 mA in 4.65s (depending on the number of MAC Addresses).

- (4) When the data collection process is completed, the microcontroller will encapsulate the data and send it to the server via the LoRaWAN protocol. Because the collected data is larger than the maximum data of a packet sent to the server, it is divided into small packages and pushed into a queue to send to the server in turn. With this process, the device used an average of 10.2mA in 13.5s.

So with the first operation, the device will consume 371uWh in total 68s (including the idle time between processes). In subsequent operations, the device only consumes energy in step (2)(3)(4), so the power consumption is reduced to 200uWh. Therefore, the device can reduce energy consumption in step (3) in the number of GNSS satellites eligible for distance calculation.

In addition to active power, the device's sleep state also consumes 26.6uA. Based on the above measurement results, the research team can calculate the device's lifetime until the energy source is exhausted. In the case of using a battery with a capacity of 1500mAh and updating data to the server once every hour, it can provide power for the device to operate for more than two years.

TABLE II: Power consumption

Task	Duration	Average Current	Phase
Join request	9.3s	5.84mA	Active
Synchronize	21.7s	4.92mA	Active
GNSS scan	4.5s	3.96mA	Active
Wifi scan	4.65s	8.51mA	Active
Send data	13.5s	10.2mA	Active
Sleep	configure	26.6uA	Sleep

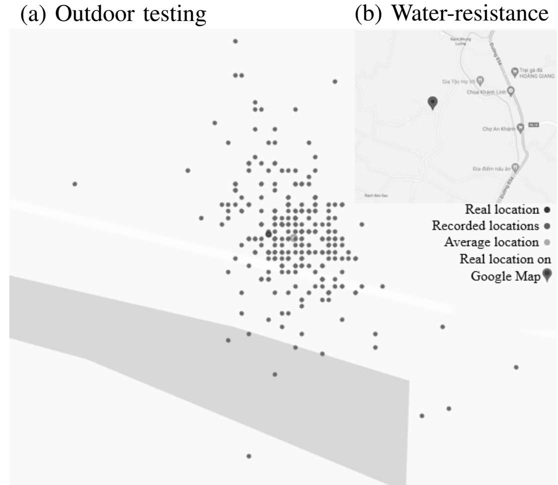
B. *Positioning Accuracy of System*

Besides the problem of energy consumption, the accuracy of the device was also measured by the research team.

For GNSS positioning, the device is placed in an unshielded location, ensuring communication with GNSS satellites. The data will be updated by device every 300s for one day. The collected data is shown in figure 8. The red dot is the device's actual location based on the coordinates on Google Maps, the blue dots are the location collected by the widget, and the green dot is the average position of the measured results. With this measurement, the maximum error is 81m, and the lowest is 1m. The results also show that the average error of this measurement is 6m.

Figure 9 shows the result of indoor positioning. The locator is placed in an area where GNSS satellites are shielded. Therefore, the number of satellites is not enough to determine the location, so WiFi-Scan is the method used. Besides, to determine by this method, the number of WiFi routers at the location must be greater than or equal to two. With the obtained results, it can be seen that the stability is not optimal. The maximum error can be up to about 75m. The mean error of these test results is more than 15m.

(a) Outdoor testing (b) Water-resistance



(c) Result of collection

Fig. 8: Outdoor testing

Fig. 9: Indoor results

IV. Conclusion

This proposal is built based on guidelines and tested indoor and outdoor scenarios. The measurement obtained the average error result of 6m for GNSS and more than 15m for WiFi Scan. In addition, the device is packaged in a box that is dust and water-resistant at an IP65 level. The device's power consumption may drop to the level of 26.6uA in the sleep state.

The system is highly applicable, integrated, and extensible in practice. Thanks to the long-distance transmission and energy-saving characteristics of LoRa, it can be applied in areas not covered by WiFi or 3G/4G. Regarding the development direction of the topic, the researchers can focus on the collected data, build machine learning models with the ability to analyze, and give lower error results.

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