Indoor Positioning System using UWB and Kalman filter to increase the accuracy of the Localization System

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***Abstract*—In this paper, an effective indoor positioning system using Ultra-Wideband (UWB) technology with modified Kalman filter is proposed. The system includes several embedded hardware devices to transmit and receive data via UWB; a Kalman filter applies to reduce noise in the signal for increasing the accuracy; a software stacks to calculate the position using Time Difference of Arrival (TDOA) and trilateration algorithm, then store the data. The system also comes with a graphical user interface to monitor the data and control remotely.**

Keywords: Indoor Positioning, Ultra-Wide Band, Kalman filter, Time Difference of Arrival, Internet of Things

I. INTRODUCTION

In the next generation of the industry, the Internet of Things [1] power factories and buildings to be equipped with smart and connected devices. In addition, the advantages of nowadays technology make electronic devices in compact size, connected and promoting almost aspect of modern human living. The challenge is how to locate a device indoor so that the management system can behave effectively in both power consumption and convenience [2]. There are several radio-based technologies can overcome this challenge. For examples, NB-IoT, LoRa, Ultra-Wideband... with different considerable properties like working distance, radio frequency (RF) bands, transmission bandwidth, transmission speed, transmission power. The selection of which one of these core technologies to be used makes a tremendous impact on the whole system application, which is shown in Table 1.

Table 1 Comparison between various IoT wireless technology

Properties	NB-IoT [3]	LoRa [4]	UWB [5]
Range	Under 15 km	Under 15 km	Up to 300 m
Radio Frequency	450 MHz to 3.5 GHz	From 433 MHz to 2.4 GHz, depends on region	From 3.5 GHz to 6.5 GHz
Channel Bandwidth	180 / 200 kHz	From 125 KHz to 500 KHz	500 / 900 MHz
Data rates	Up to 159 kbps	Up to 21.9 kbps	Up to 6.8 Mbps
Transmission Power	14 / 20 / 23 dBM	2 to 20 dBM	10 / 14 dBm
Battery Life	Up to 10 years[1]	Up to 10 years[1]	Up to 5 years[1]
Standard	LTE Cat NB2	LoRaWAN 1.0.4	IEEE802.15.4-2011

II. THE PROPOSED METHOD

This design promotes UWB technology because of its features, such as built-in distance measuring using two-way ranging or TDOA schemes; low power consumption down to 50 nA in DEEPSLEEP mode; and the flexible of configuration in Radio Frequency bands from 3.5 GHz to 6.5 GHz, Data Rates of 110 kbps, 850 kbps, 6.8 Mbps. The higher data rates, the lower time keeping the device on-air [5, 6]. We embed the essential components in these system hardware devices, which can be configured to operate in anchor mode (anchor device), or tag mode (tag device). In anchor mode, it permanently mounted the device in corners. A tag device will be attached to a target to be located inside the area.

Fig.1 illustrates how a tag device is by 3 anchor devices in two-dimension space. Tag device first sends out data packets, called "blink", to all nearby anchors. After the anchor devices receive the packets, each device measures the distance between itself and tag device. This operation is performed in-device automatically. After the measurement, it sent the data to an edge device to apply a Kalman filter for better accuracy [7]. The accuracy is determined:

$$Accuracy = 100 \times \left| 1 - \frac{D_k}{D_m} \right| \quad (1)$$

where D_k is the average error distance by Kalman filter, and D_m is the map border size.

Now the edge device can locate the position of the tag device using TDOA and trilateration algorithm [8]. Further processing methods are localization, data storage, visualization and remote control. Fig. 2 shows the entire process.

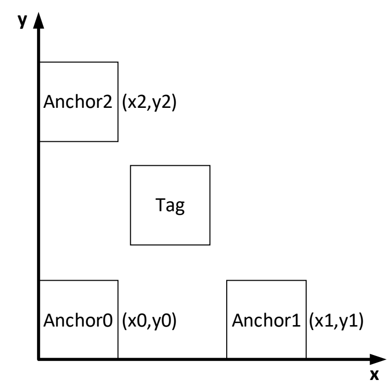

Fig. 1 Locating tag device using TDOA and trilateration algorithm.

III. SYSTEM INTEGRATION

In this paper, we implement the embedded hardware devices using STM32-F1 microcontroller and Decawave DW1000 UWB module. The system includes minimal 3 and maximal 4 anchor devices, it can set localization targets up to 8 tag devices, a Raspberry Pi 3 board as an edge device for could data communication. A digital indoor localization map is pre-defined and being used to visualize located tag devices. User can monitor and control devices remotely using a user graphics interface on a website.

IV. EXPERIMENTAL RESULTS

After the system installation, it ran many tests in following conditions: we changed the size of map in factor of 5, the number of routes was from 1 to 4 routes, and there was no obstruction between the transceivers. The system achieved positive results. According to

[1]Depends on RF, bandwidth, data rates and transmission power configuration

Table 2, when changing the shape of route, the accuracy of the filter changes slightly (illustrated in Fig. 3). When the system combines a Kalman filter with UWB positioning (illustrated in Fig. 4), the accuracy has decreased down to 5.3 cm with the average accuracy of 94.7%~99.45%.

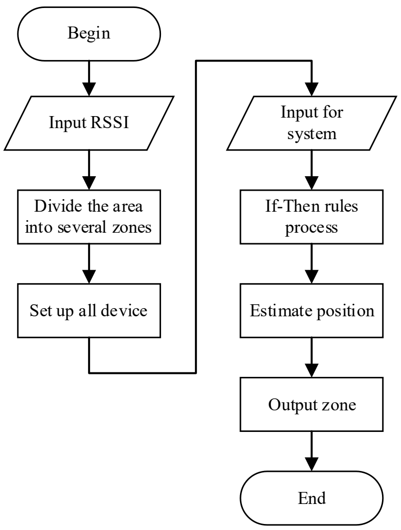

Fig. 2 Zone positioning program flow.

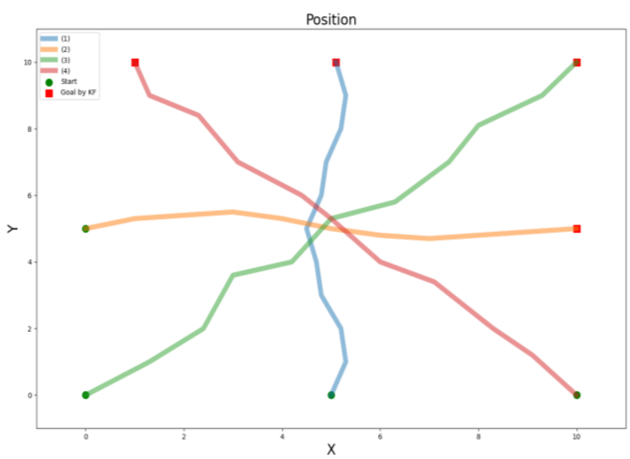

Fig. 3 Records of localization target's moving routes.

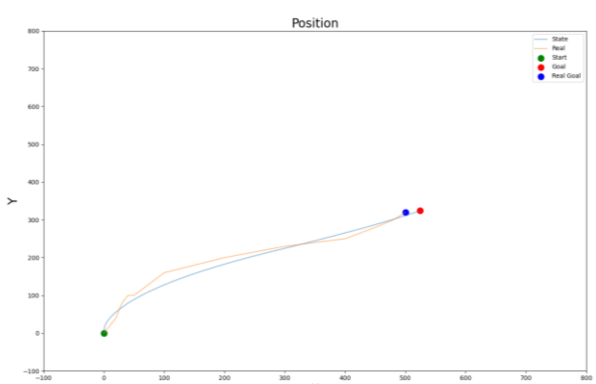

Fig. 4 Result of Kalman filter with UWB TDOA algorithm.

Table 2 Result of Kalman filter.

Size of map (m)	Routes	Kalman filter with accelerator sensor			Kalman filter with accelerator sensor and UWB positioning		
		Error (cm)	Average Error (cm)	Average Accuracy (%)	Error (cm)	Average Error (cm)	Average Accuracy (%)
1x1	(1)	14.8	13.9	86.1	5.4	5.3	94.7
	(2)	14.3			5.3		
	(3)	13.9			5.9		
	(4)	12.6			4.6		
5x5	(1)	14.8	14.95	97.01	6.8	6.5	98.7
	(2)	14.9			6.7		
	(3)	14.7			6.9		
	(4)	15.4			5.6		
10x10	(1)	16.8	16.85	98.32	7.8	7.9	99.21
	(2)	16.3			8.3		
	(3)	16.7			7.9		
	(4)	17.6			7.6		
15x15	(1)	18.8	18.625	98.76	8.2	8.25	99.45
	(2)	18.3			8.3		
	(3)	18.8			7.9		
	(4)	18.6			8.6		

V. CONCLUSION

Development of wireless technology allows us to design more compact and efficiency indoor positioning system. UWB is a typical candidate contributing to the success of the system. This system design could be more optimized in both hardware and software size to reduce the power consumption. Hence, the design could be directly integrated into mobile phones, housewares and industrial devices for more convenience. However, a disadvantage of UWB is the having short working range, which should be improved in design or adapted with new technology in the future.

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