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INDOOR LOCALIZATION SYSTEM USING UWB

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***Abstract**. This paper discusses two ways of measuring the distance between the transmitter and the receiver using UWB technology, then identifies their advantages and disadvantages. The method of calculating the position is presented together with the method of predicting errors based on room geometry. The hardware configuration of the transmitter and receiver systems included in a location system based on UWB technology is explained. Bluetooth technology is discussed, which is used to connect the location system with the environmental monitoring system.*

Keywords: bluetooth, identity management systems, indoor radio communication, logistics, navigation, ultra-wideband technology

WEWNĘTRZNY SYSTEM LOKALIZACJI Z WYKORZYSTANIEM UWB

***Streszczenie.** W niniejszym artykule omówiono dwa sposoby pomiaru odległości między nadajnikiem, a odbiornikiem wykonanymi w technologii UWB, następnie określono ich wady oraz zalety. Przedstawiono sposób obliczania pozycji wraz z metodą przewidywania błędów w oparciu o geometrie pomieszczenia. Wyjaśniono konfigurację sprzętową nadajnika oraz odbiornika układów wchodzących w skład systemu lokalizacji opartych o technologię UWB. Omówiono technologię Bluetooth, która wykorzystana została do połączenia ze sobą systemu lokalizacji wraz z systemem nadzorowania warunków środowiskowych.*

Słowa kluczowe: bluetooth, komunikacja radiowa wewnątrz pomieszczeń, logistyka, nawigacja, systemy zarządzania tożsamością, technologia ultra szerokopasmowa

Introduction

Accurate determination of the position of objects and people in closed spaces with high accuracy is something desired by the consumer and industrial market. GPS technology that works properly in open space and provides accuracy on the level of several dozen meters, which is sufficient to locate the building. For a simple location inside the building, it is possible to use Bluetooth beacons that calculate the distance based on the RSSI, which gives the measurement accuracy within one to two meters. However, in confined spaces such as warehouses, much higher accuracy is required. Therefore, for indoor locations where high accuracy of location measurement is required, a technology that ensures accuracy at the level of several to several dozen centimetres should be used. The best solution to the problem of indoor location is to use UWB technology with the calculation of the location of the object based on the response time of the transmitter. In UWB technology, it is also possible to calculate the position based on the RSSI. RTLS (Real-Time Location System) is based mainly on UWB (Ultra-Wide Band) technology, which works in high-frequency radio technology with a wide signal band [1].

1. The methods of measuring distance

In UWB technology, two distance measurement methods can be distinguished, such as RSSI (Received Signal Strength Indication) and ToF (Time of Flight) measurement. The first method discussed is the localization of objects using RSSI. It allows determining the signal strength between the sensor and individual anchors, in this method one transmitter and one receiver is used. This method is presented in figure 1. The accuracy of object localization is in the range of 0.5 m – 1 m. Equation 1 presents the method of calculating RSSI:

$$RSSI = 10log_{10}\left(\frac{C2^{17}}{n^2}\right) - A[dBm] \quad (1)$$

where:
C – channel impulse response power,
N – number of preamble accumulation,
A – constant name of the transmission frequency.

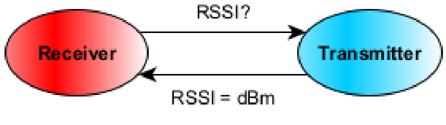

Fig. 1. Method of distance measurement by asking for RSSI

The individual values can be read from the internal registers of the device. The calculated value is expressed in dBm. It is the unit of absolute level related to the power of 1 mW. The method used is an estimation method, i.e. it gives an approximate value of signal power.

The second discussed the method of determining the distance is ToF (Time of Flight). The simplified principle of operation is shown in figure 2. The operation of this method consists in determining the time of flight of the frame between the transmitting and receiving device. Knowing the time of transmission and the speed at which radio waves move (the speed of light) we can determine the distance with high accuracy. This method allows for tracking many objects at the same time and makes it possible to locate them with the accuracy of several dozen centimetres. The disadvantage of this method is the necessity of having at least three receivers so that the measuring system could determine the position in space in an unprecedented way [2].

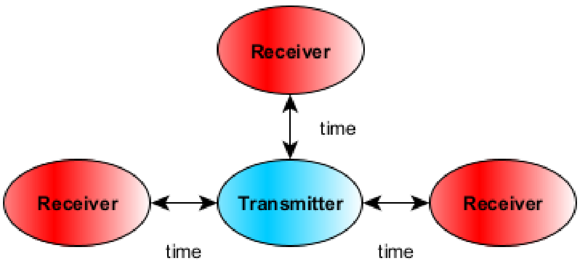

Fig. 2. Method of measuring distance by measuring the response time

Figure 3 shows the principle of trilateration, which is used to locate objects, a similar localization method is used by GPS. Equations 2, 3, and 4 show how to calculate the location of an object in two-dimensional space. The distances d1, d2, d3 are calculated based on the response time of the transmitter. Furthermore, in this localization method, the position of the anchors in the room under study must be considered. To obtain the transit time, the sensor sends a frame while specifying the send time. After receiving the frame the particular anchor determines the time of receiving the frame and the expected time of sending the frame, which are included in the return frame [7]. After receiving the return message, the sensor determines the transit time taking into account the time needed for operations performed by the anchor. In order to obtain the most accurate result, the software also takes into account the antenna delay i.e. the time needed for the antenna to propagate the received signal. The obtained value determines the round trip time, so it should be divided into two. In the final stage the obtained value should be multiplied by the speed of light, which gives the final value of the distance between the sensor and the anchor expressed in centimetres. With proper calibration, it is possible to achieve an accuracy of ±10 cm [4].

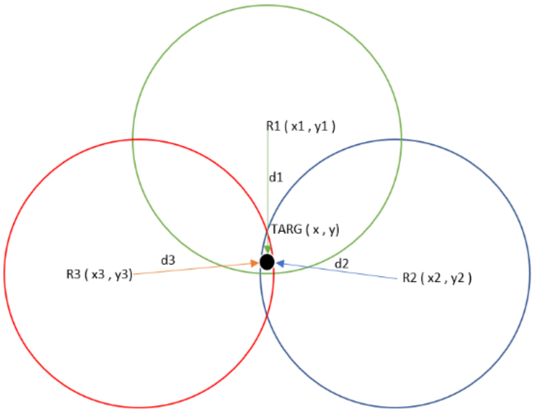

Fig. 3. Trilateration estimation

The distances d_i are given by the following equation:

$$\begin{cases} d_1 = (x_1 - x)^2 + (y_1 - y)^2 \\ d_2 = (x_2 - x)^2 + (y_2 - y)^2 \\ d_3 = (x_3 - x)^2 + (y_3 - y)^2 \end{cases} \quad (2)$$

Solving this system of equation reveals the tag position (x, y) as follows:

$$x = \frac{Ay_{32}+By_{13}+Cy_{21}}{2(x_1y_{32}+x_2y_{13}+x_3y_{21})} \quad (3)$$

$$y = \frac{Ax_{32}+Bx_{13}+Cx_{21}}{2(y_1x_{32}+y_2x_{13}+y_3x_{21})} \quad (4)$$

where:

$$\begin{cases} A = x_1^2 + y_1^2 - d_1^2 \\ B = x_2^2 + y_2^2 - d_2^2 \\ C = x_3^2 + y_3^2 - d_3^2 \end{cases} \quad (5)$$

$$\begin{cases} x_{32} = x_3 - x_2 \\ x_{13} = x_1 - x_3 \\ x_{21} = x_2 - x_1 \end{cases} \quad (6)$$

$$\begin{cases} y_{32} = y_3 - y_2 \\ y_{13} = y_1 - y_3 \\ y_{21} = y_2 - y_1 \end{cases} \quad (7)$$

The highest measurement accuracy can be achieved in rooms with simple geometry, in which there are no objects blocking or attenuating the electromagnetic wave (laboratory conditions). In order to improve the accuracy of the measurements, measurement errors should be determined. The formula for calculating the mean square error was used to determine the measurement errors (equation 7). In statistics, the mean squared error of an estimator measures the mean squared error, i.e. the mean squared difference between the estimated values and the true values an example is shown in figure 4 [3] .

$$MSE = \frac{1}{n}\sum_{t=1}^{n}(y_t - y_y^P)^2 \quad (8)$$

where:
n – number of data points,
t = 1, 2, 3, …, n,
y_t – observed value,
y_t^P – predicted value.

Fig. 4. Average squared error

Table 1. Differences between RSSI and ToF measurement method

Method of measuring	RSSI	Response time
Accuracy of measurement	1-2 m	10-40 cm
Minimal number of receivers (anchors)	1	3
Data acquisition time	Fast	Slow
The complexity of the measurement system	Easy	Complicated

2. Hardware

The design of the device was based on the following assumptions:

- possibility of battery and external power supply,
- small size,
- control unit with Bluetooth communication module,
- sensors for environmental conditions,
- as simple as possible design.

The designed device consists of three main sections:

- power supply section,
- section with the NRF52832 control circuit,
- section with the radio module,
- section with the sensor environmental conditions.

The power supply system has been designed to be powered from batteries (Li-Ion and Li-Pol) or from an external power source. The external power supply has been separated from the measurement system by an isolated DC/DC converter due to the high sensitivity of radio systems to conducted interference. Additionally, an external power source is used to charge the electrochemical cell. For this purpose, the BQ24092DGQT chip is used, which manages the working of the battery and enables its charging. To be able to switch between power sources, an additional P-MOSFET transistor is used to switch on the power from the battery if the power cable is not connected.

For the NRF52832 chip, an additional external antenna was required. It was decided to use the 2450AT18A100E single-chip antenna. This antenna was designed for 2400–2500 MHz, the frequencies most suitable for Bluetooth applications. The UWB chip used has a built-in omnidirectional antenna which guarantees similar output signal gain in different directions.

In addition, the project used environmental condition sensors such as a temperature sensor, a humidity sensor, and a pressure sensor. All sensors used the I2C data bus. The anchor and sensor used the same schematic and PCB. In the case of anchor, sensors were not soldered as well as batteries were not connected as they were powered from the external power source. Figure 5 shows a simplified schematic diagram of the transmitter and receiver (differences in the internal structures of the devices are visible).

The device also uses additional elements such as diodes, buttons, and connectors. The diodes used allowed, among other things, to verify the correctness of the device's power supply or battery charging. The use of buttons allowed to reset the device and influence the program operation.

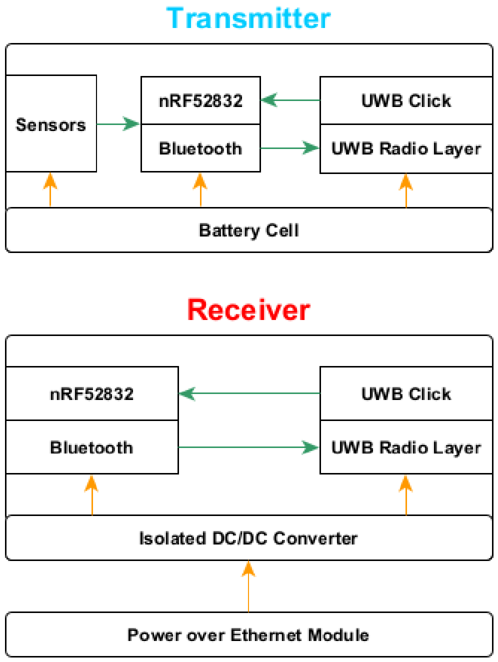

Fig. 5. Simplified circuit diagram

The following figure shows the electrical diagram of the building location system. When designing the scheme, an attempt was made to reduce its complexity, therefore a ready-made UWB module was used.

Based on the schematic diagram, a PCB design was created. It is a double-sided PCB with a thickness of 1.6mm. The external dimensions of the board are approximately 35 mm × 45 mm. Elements responsible for communication, i.e. UWB module and Bluetooth antenna are placed in the upper part of the device. This solution was decided upon in order to avoid signal interference and to achieve the most stable microwave and Bluetooth communication.

The DW1000 microwave module only requires a power supply and an SPI communication bus for basic operation. To ensure its proper operation, it was decided to use paths of the same length for each of the bus signals. A suitable design environment tool was used for this purpose. To equalize the length of the paths, it increases the length of the individual tracks by wrapping them in a small area.

For Bluetooth communication to work properly, it was necessary to adjust the impedance of the antenna path to a value of 50 Ω. To do this, a built-in Altium Designer environment tool was used to adjust the width of a given path to achieve the required impedance[5].

Mounting holes are also provided in the PCB design. This allows the device to be easily fixed in the enclosure. Figure 7 shows a 3D visualization of the developed PCB forming the in-building navigation system.

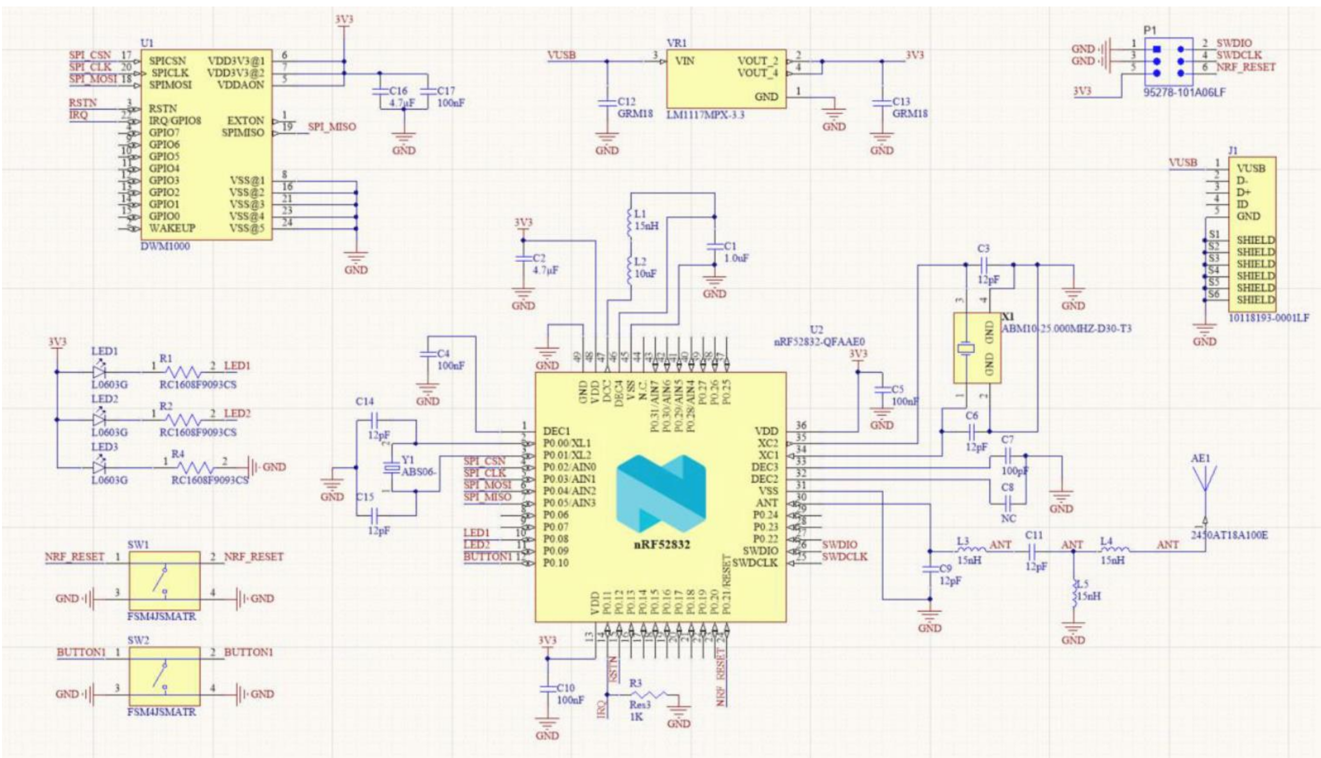

Fig. 6. Electrical diagram of the device

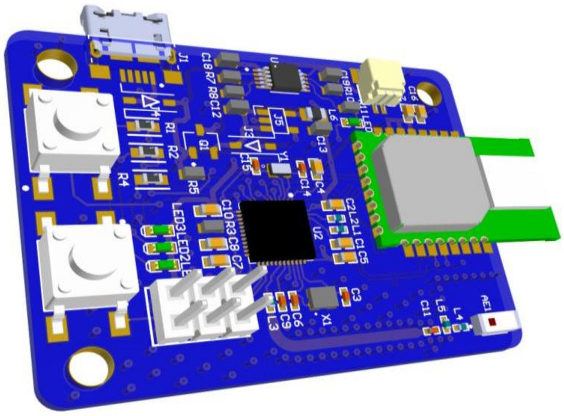

Fig. 7. 3D visualization of the device

2.1. Findings

Tests of the designed distance measuring system were carried out in laboratory conditions, i.e. in a 5 m × 5 m room with anchors placed in the corners of the room. Figure 8 shows a view of the room described. There were no objects in the room that could interfere with the signal emitted by the transmitters or receivers. The measurement procedure was started remotely using Bluetooth technology. The measurement started when a value of 1 was sent to a given anchor and then a return message of 0 was awaited. The message was sent via the Bluetooth UART service [5, 7].

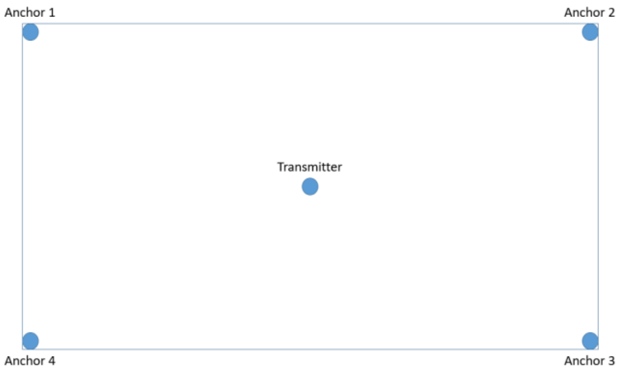

Fig. 8. Simplified diagram of the room

The mounts were designed to be attached to the wall with double-sided tape. The bracket has an articulated joint that allows the tilt of the mounted device to be adjusted. A view of the holder is shown in figure 9.

Fig. 9. Handle made with 3D printing technology

Before the measurements were made, the way in which the tests were to be carried out was defined, so the tests were carried out as follows:

- measuring the distance of the marker from the anchor with a measuring device,
- the transmitting and receiving devices shall be at the same height,
- return of antennas in the same position.

During the distance measurement with the UWB devices, the distance between the transmitting and receiving devices was measured simultaneously with a tape measure. This measurement allowed to verification the results obtained from the developed device. In addition, to make the measurements reliable and repeatable for each device, they were positioned so that they were at the same height. Additionally, the transmitting devices were directed so that the UWB antenna in the transmitter was facing the anchor. The reason for such an arrangement was to reduce interference resulting from wave reflections from walls as well as to shield the signal power in the form of printed circuit boards present on the PCB. Positioning the antenna in an appropriate way was very important in the case of testing the measurement method based on RSSI.

The graph below shows the signal measurement series. The sensor was moved closer to each anchor in turn, which is well reflected in the graph. It can be seen that as the distance increases, there is a greater scatter in the values received from the measuring system. The scatter of the measured values may be due to overlapping of the waves reflected from the walls of the room or incorrect positioning of the devices in relation to each other.

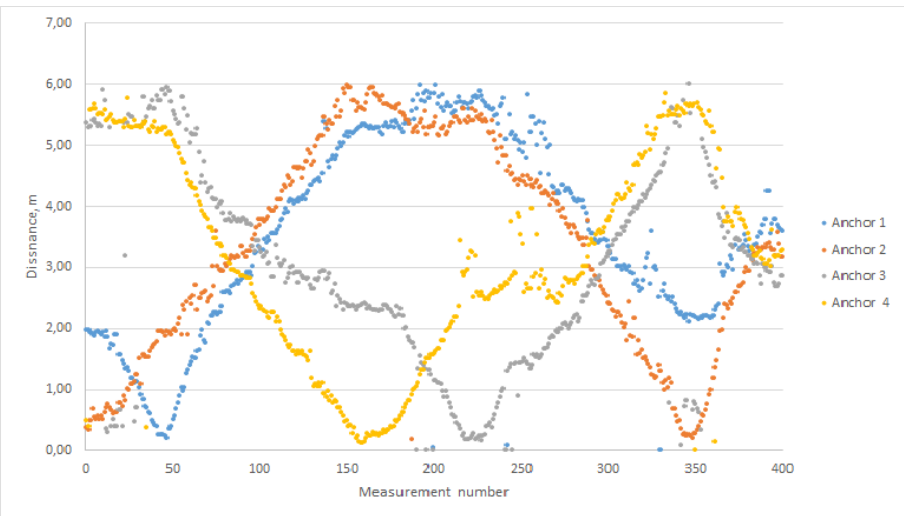

Fig. 10. Graph of the distance between individual anchors and the sensor

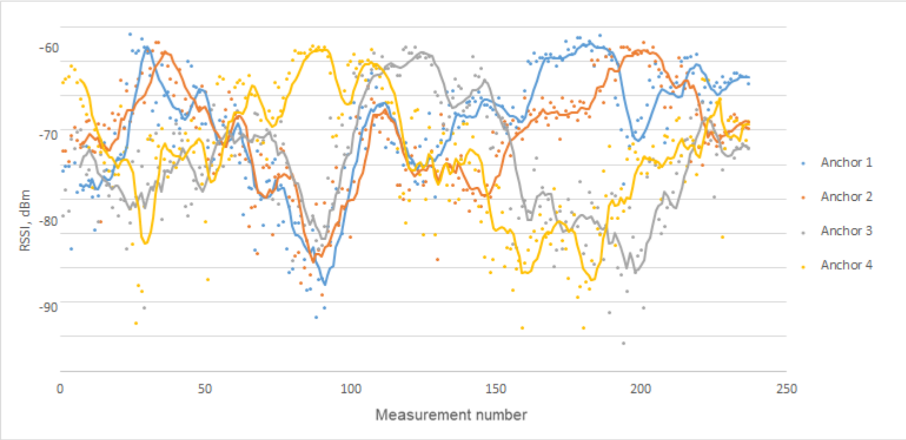

Fig. 11. Graph of RSSI values for individual anchors

The distortion in the RSSI method is much higher compared to the ToF method (this is shown in the figure 10). It can be observed that the greater the distance between the transmitter and the receiver, the less stable the signal strength was.

To make the graph more readable, a trend line based on the moving average of the values has been added to each series. This makes it clear when the market has moved away from a given anchor and when it has moved towards it. The distortions shown in figure 10 are most likely due to disturbances caused by electromagnetic waves reflecting off walls or imperfections in the antenna radiating the signal.

3. Summary

This paper presents a complete demonstration of UWB's indoor location. Two indoor localization methods are described, namely, a distance measurement method using signal strength determination (RSSI) and a frame transit time (ToF) measurement method. The research shows that the RSSI method is less accurate than the ToF method. After analysing the results obtained from RSSI measurement it was concluded that this method will not be taken into account in further works on the localization system due to easy interference and fluctuations of signal strength for unknown reasons. The measurement accuracy for the ToF method ranged from 10 cm – 50 cm. Some of the measurement errors could be due to imperfections related to and manual setting of the transmitter position. The ToF method, despite the longer data acquisition time, achieved much higher accuracy and was more resistant to interferences, which can be observed in the previously presented graphs.

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