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Precise indoor location system using Ultra-Wideband technology

***Abstract**. This article discusses two ways of measuring the distance with UWB technology and then identifies the advantages and disadvantages of the methods discussed. Measurement results for the measurement methods discussed are presented. The RSSI from which the distance can be calculated is also presented, as well as how to calculate the distance for the ToF method.*

***Streszczenie.** W niniejszym artykule omówiono dwa sposoby pomiaru odległości z wykonanymi w technologii UWB, następnie określono wady oraz zalety omawianych metod. Przedstawiono wyniki pomiarów dla dla omawianych metod pomiarowych. Zaprezentowano również sposoby obliczania RSSI na podstawie której możliwe jest obliczenie odległości, oraz sposób obliczania odległości dla metody ToF (**System precyzyjnej lokalizacji w pomieszczeniach z wykorzystaniem technologii Ultra-Szerokopasmowej**).*

Keywords: Ultra-wideband technology, Navigation, Identity management systems, Indoor radio communication.
Słowa kluczowe:. Technologia ultra szerokopasmowa, Nawigacja, Systemy zarządzania tożsamością, Komunikacja radiowa w pomieszczeniach.

Introduction

Many different optimization methods are used in detection technologies [1-9]. Precise determination of the location of objects and people in confined spaces with high accuracy is in demand in the consumer and industrial markets. GPS technology, which correctly locates in open spaces, does not meet its objectives in enclosed objects. For simple indoor locations, Bluetooth transmitters that calculate distance based on RSSI can be used, resulting in measurement accuracy of one to two metres. Therefore, in indoor locations with a large number of objects to locate, where high accuracy of location measurement is required, technology that allows localization to a few centimetres should be used. The best solution to the problem of indoor location is to use UWB technology, which is additionally resistant to electromagnetic interference. Two localisation methods are distinguished in the UWB technology, namely RSSI and ToF. The RTLS (Real-Time Location System) is mainly based on UWB (Ultra-Wide Band) technology, which operates in high-frequency radio technology with a wide signal band [10].

RSSI measurement

RSSI (Received Signal Strength Indication) signal strength measurement can be used to estimate the distance between transmitter and receiver quickly, and this method provides very fast data acquisition. The disadvantage of this measurement method is the low accuracy in the range of 1m to 2m, making it unlikely to determine the position of several objects in close proximity [11]. The accuracy of signal strength measurement is affected by phenomena such as the reflection of electromagnetic waves from various surfaces and absorption by some objects. These effects mean that the received signal strength does not behave in a linear manner. The following formula shows how signal strength is calculated by receiving and transmitting devices [12].

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

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

Signal power can be measured in two ways. The first way is to ask the receiver for the signal strength and then get a response, as shown in Figure 1. The second way is to measure the signal strength directly through the transmitter, as shown in Figure 2. The choice of measurement method has no effect on the accuracy of the results but has a large impact on the energy consumption when using an electrochemical cell in the transmitter, as continuous listening to the transmitting channels consumes more energy.

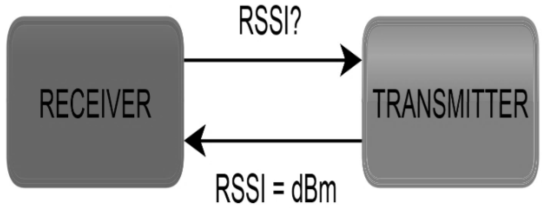

Fig. 1 RSSI measurement with response

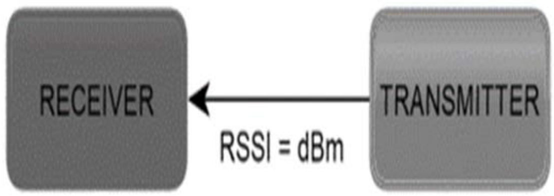

Fig. 2. RSSI measurement without response

ToF (Time of Flight) measurement

The ToF (Time of Flight) distance measurement method is shown in Figure 3. The operation of this method is based on determining the time of flight of a frame between the transmitting and receiving devices. Knowing the transmission time and the speed at which the radio waves travel (speed of light), it is possible to determine the distance with a high degree of accuracy [13]. This method allows multiple objects to be tracked simultaneously and makes it possible to locate them with an accuracy of several tens of centimetres. The method is characterized by high precision in determining the distance between the transmitter and receiver [14].

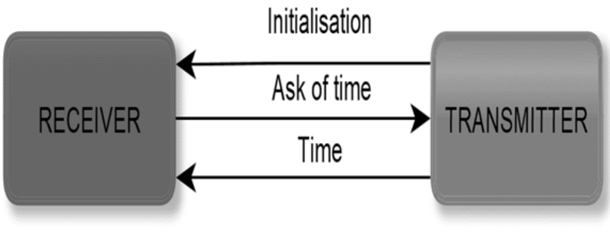

Fig. 3. Method of measuring distance by measuring the response time

The formula below shows how to calculate the distance between the anchor and the transmitter, the formulae in are simplified as the time t1 and t2 are fully dependent on the operating frequency of the microcontroller, the delay of the antenna used and the transmission channel is chosen [15].

(1) $$tof = \frac{(t_1 - t_2)(1 - clk)}{2}$$

(2) $$d = t_{of} \cdot c \cdot 100$$

where: t1 - initialisation time, t2 - data reception time, clk - clock offset, tof – time of fly, c - speed of light

The high measurement accuracy makes it possible to determine the location of people and objects in the monitored room. The time-of-flight system used to determine distances can be used for indoor navigation, making it significantly easier to find a destination. Such a system can be used, for example, in large shopping centres, airports or warehouses. Accurate localisation operating in less than 10 ms allows it to be used for access control management, e.g. the system recognises that a person is approaching a door and, if that person has access rights to the room, the door is opened without the need for objects to open it [16]. The very precise determination of the distance continuously results in higher power consumption.

Hardware solution

The following assumptions were made in the design of the electrical anchor scheme:

- Small size,
- Power supply and data transmission via PoE power supply
- Anchor configuration via Bluetooth protocol
- Wide range of supply voltage

The use of UWB technology is enabled by the DW1000 module, which was configured via the SPI (serial peripheral interface) bus. The device's main microcontroller is the STM32F746IGK, which was responsible for communicating with an external server using the Ethernet standard and controlling the UWB module. The configuration of basic parameters, such as the device name, was done by the NRF52832 microcontroller with the Bluetooth wireless communication module. All circuits present on the board were powered by a DC/DC converter, which reduces the voltage supplied by the PoE power supply. The PoE power supplies provide a voltage range of 12 to 52 VDC, so the converter had to be adapted to this voltage range. The converter used was non-isolated to reduce the size of the PCB. The converter reduces the voltage to 5 VDC and then a stabiliser is used to stabilise the voltage from 3.3 VDC, which was used to power all the ICs on the PCB.

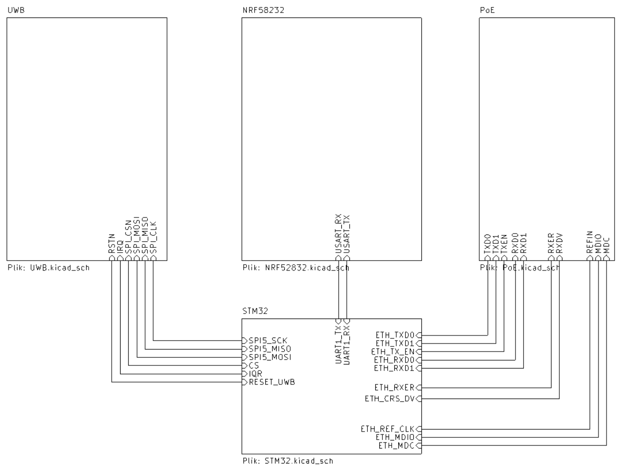

Fig. 4. Block diagram of UWB circuit

The 3D model of the UWB anchor is shown in the figure below. The anchor was designed according to the previously made electrical schematic shown in Figure 4. Figure 4 shows the block diagram, as it would be unreadable to present all the components of the schematic

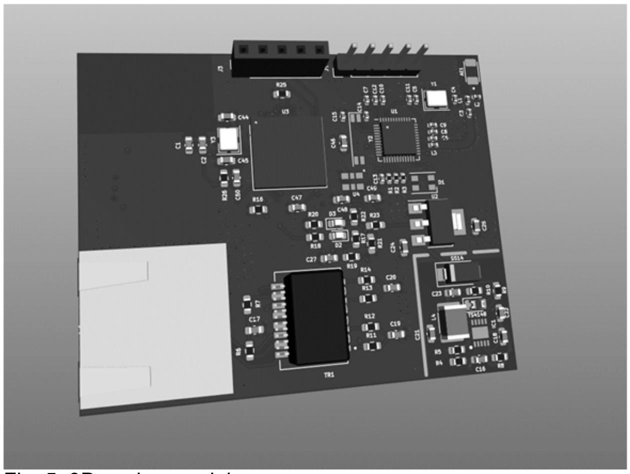

Fig. 5. 3D anchor model

The fabricated device was used to perform the research presented in this article.

Result

Knowing the basic technical parameters of the distance measurement methods discussed, it is possible to select the appropriate localization method depending on the expected results. In the case of locating single objects in a small space, RSSI-based localization will be suitable due to its low energy consumption. However, in the case of locating multiple objects in a large space, the ToF-based localization method will be the most optimal, especially when the localized objects are close to each other. Table 1 shows the differences between object localization based on distance measurement methods through signal strength (RSSI) and the ToF frame transit time calculation method.

Tab. 1. Differences between RSSI and ToF measurement method

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

The following graphs show the results of RSSI signal strength measurements between individual receivers (anchors) and one transmitter

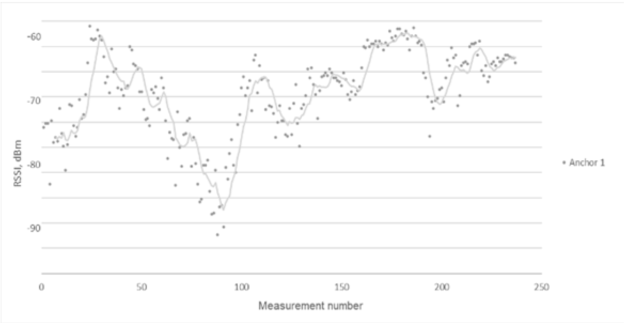

Fig. 6. Graph of RSSI values for anchor 1

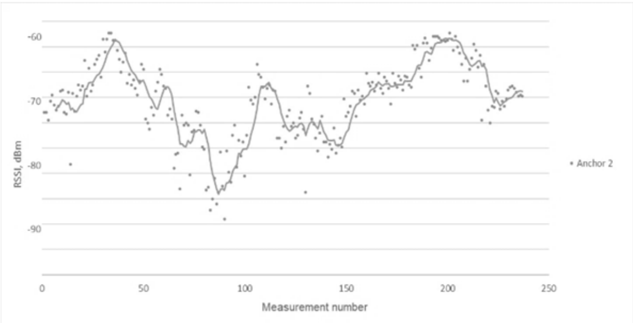

Fig. 7. Graph of RSSI values for anchor 2

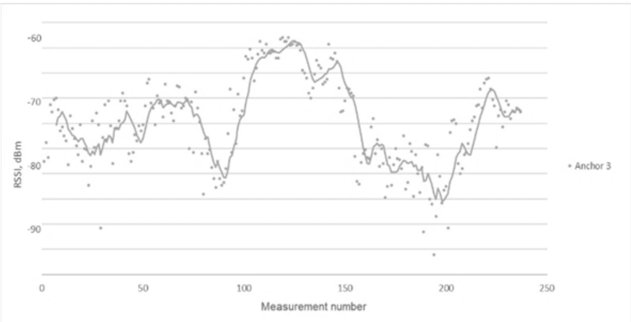

Fig. 8. Graph of RSSI values for anchor 3

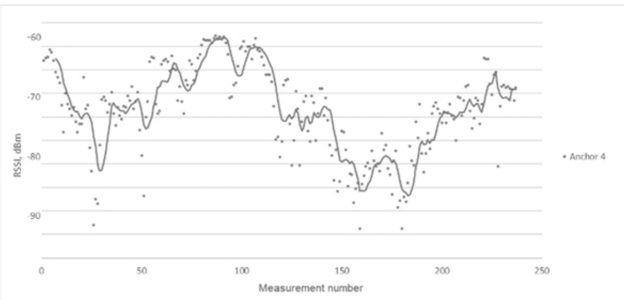

Fig. 9. Graph of RSSI values for anchor 4

To make the chart more readable, a trend line based on a moving average value 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 previously discussed drawbacks of RSSI measurement, i.e. the instability of signal strength depending on distance, can be read off the graph. During the measurements, the signal power varied significantly (approx. ±9 dBm) even when there was no change in the distance between the anchor and the transmitter.

The figures below show the results of distance measurements using the ToF method. It can be seen that the results are stable and do not change in a stepwise manner compared to the RSSI measurement method

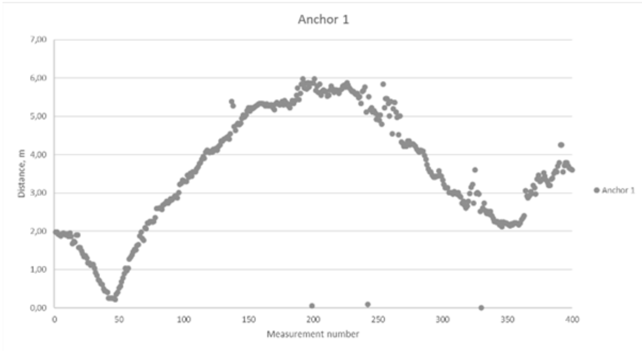

Fig. 10. Graph of ToF values for anchor 1

Fig. 11. Graph of ToF values for anchor 2

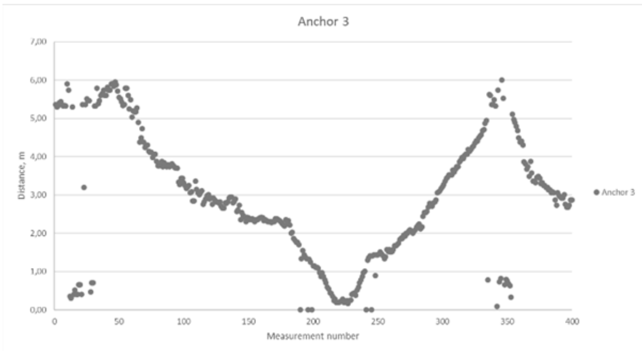

Fig. 12. Graph of ToF values for anchor 3

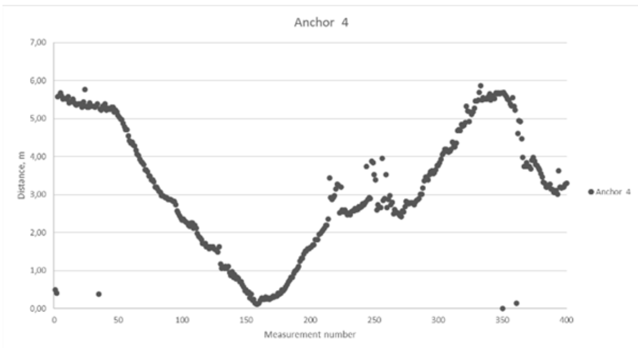

Fig. 13. Graph of ToF values for anchor 4

Comparing the results in the method RSSI and Tof, it can be seen that the distortion in the RSSI method is significantly higher compared to the ToF method. In the RSSI method of measuring signal power, it can be seen that the greater the distance between transmitter and receiver, the more stable the signal power becomes. The choice of the appropriate distance measurement method depends on the expected end results. In the case of searching for single objects in a limited space, distance measurement based on RSSI proves to be a better solution, as the measurement accuracy is acceptable in many cases, and relatively small batteries can be used. In the case of locating multiple objects in large spaces and especially when the objects are very close to each other, a system based on the ToF measurement method is the best solution due to its high accuracy. The disadvantage of this system is the high power consumption of the transmitting equipment.

During the testing of the ToF distance measurement method, it was noted that there was some interference during the measurements. It was therefore decided to carry out stability measurements by placing the transmitter in one position and taking 400 measurements. The graph below shows the results of the measurements.

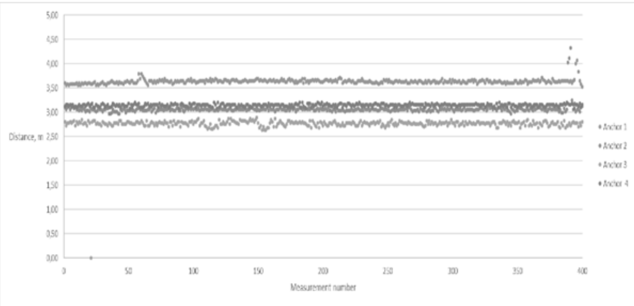

Fig. 14. Signal stability measurement in the ToF method

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