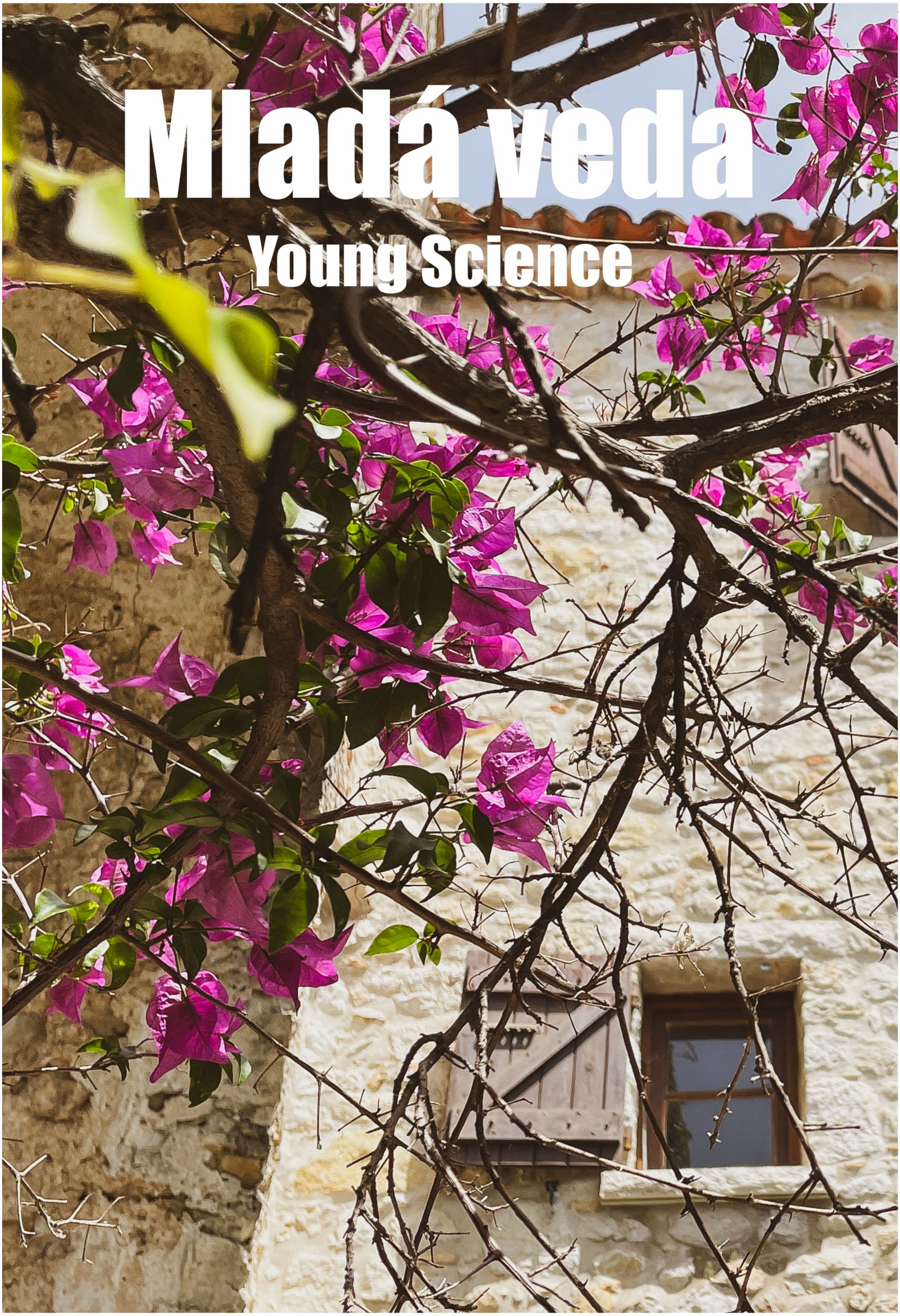
ISSN 1339-3189

2/2024

Mladá veda

Young Science



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Young Science

MEDZINÁRODNÝ VEDECKÝ ČASOPIS MLADÁ VEDA / YOUNG SCIENCE

Číslo 2, ročník 12., vydané v júni 2024
ISSN 1339-3189, EV 167/23/EPP
Kontakt: info@mladaveda.sk, tel.: +421 908 546 716, www.mladaveda.sk
Fotografia na obálke: Èze, Francúzsko. © Branislav A. Švorc, foto.branisko.at

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Vydavateľstvo UNIVERSUM, spol. s r. o.
www.universum-eu.sk
Javorinská 26, 080 01 Prešov
Slovenská republika

Mladá veda
Young Science
ISSN 1339-3189

Vol. 12 (2), pp. 125-132

EXPERIMENTÁLNE TESTOVANIE VNÚTORNÉHO LOKALIZAČNÉHO SYSTÉMU ZA ÚČELOM POSÚDENIA PRESNOSTI A SPOĽAHLIVOSTI URČOVANIA POLOHY

EXPERIMENTAL TESTING OF THE INDOOR POSITIONING SYSTEM TO ASSESS THE ACCURACY AND RELIABILITY OF THE POSITION DETERMINATION

Erika Skýpalová, Martin Boroš [1]

Erika Skýpalová pôsobí ako interná doktorandka na Fakulte bezpečnostného inžinierstva Žilinskej univerzity v Žiline. Vo svojom výskume sa venuje problematike vnútorných lokalizačných systémov z hľadiska realizovania experimentálnych testovaní zameraných na skúmanie vplyvu podmienok uzatvorených priestorov na kvalitu a schopnosť šírenia signálu pre účely určovania polohy osôb a entít v interiéri budov. Martin Boroš pôsobí ako prodekan pre medzinárodné vzťahy a marketing na Fakulte bezpečnostného inžinierstva, Žilinskej univerzity v Žiline. Vo svojej vedecko-výskumnej činnosti sa zaoberá hodnotením spoľahlivosti a projekcií poplachových systémov a technickej ochrane objektov.

Erika Skýpalová works as an internal PhD student at the Department of Security Management, Faculty of Security Engineering, University of Žilina. In her research she deals with the issue of indoor localization systems in terms of experimental testing aimed at investigating the impact of confined space conditions on the quality and ability of signal propagation for the purpose of determining the location of persons and entities in the interior of buildings. Martin Boroš works as Vice Dean for International Relations and Marketing at the Faculty of Security Engineering, University of Žilina. In his scientific and research activities he deals with the evaluation of reliability and design of alarm systems and technical protection of objects.

Abstract

Indoor location-based systems are currently finding applications in various spheres of social life, including education, healthcare, logistics, airports, museums and smart buildings. They make it possible to manage resources more efficiently, contribute to increasing security levels

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and are also used to provide navigation services. These systems use a variety of technologies, including Wi-Fi, Bluetooth, UWB, RFID or inertial systems, which are suitable for the needs of locating people and entities and obtaining location information. Indoor location issues still face challenges, including the complexity of indoor environments or the need to ensure high positioning accuracy. As GPS signals do not sufficiently penetrate indoor building structures, it is necessary to choose a different technology that can be implemented within building interiors. This paper focuses on investigating the accuracy and reliability of the proposed indoor location system based on Bluetooth Low Energy beacon technology in terms of the system's ability to determine the location of people and entities. For this purpose, experimental testing has been carried out, whereby the movement of a person along a predefined route in an confined space has been investigated.
Key words: indoor positioning system, bluetooth low energy, beacon, received signal strength indicator

Abstrakt

Vnútorné lokalizačné systémy v súčasnosti nachádzajú uplatnenie v rôznych sférach spoločenského života, medzi ktoré patrí školstvo, zdravotníctvo, logistika, letiská, múzeá a smart budovy. Umožňujú zefektívniť riadenie zdrojov, prispievajú k zvyšovaniu úrovne bezpečnosti a slúžia i pre poskytovanie navigačných služieb. Tieto systémy využívajú rôzne technológie, medzi ktoré patrí Wi-Fi, Bluetooth, UWB, RFID či inerciálne systémy, ktoré sú vhodné pre potreby určovania polohy osôb a entít a získavanie lokalizačných informácií. Problematika vnútornej lokalizácie stále čelí výzvam, medzi ktoré patrí zložitosť vnútorných prostredí či potreba zaistiť vysokú presnosť určovania polohy. Nakoľko GPS signály nedostatočne prenikajú stavebnými konštrukciami vnútorných priestorov, je potrebné zvoliť inú technológiu, ktorú je možné implementovať v rámci interiérov budov. Článok je zameraný na skúmanie presnosti a spoľahlivosti navrhovaného vnútorného lokalizačného systému na báze nízkoenergetickej technológie Bluetooth beaconov z hľadiska schopnosti systému určovať polohu osôb a entít. Za týmto účelom bolo realizované experimentálne testovanie, pričom bol skúmaný pohyb osoby po vopred definovanej trase v uzatvorenom priestore.
Kľúčové slová: vnútorný lokalizačný systém, nízkoenergetická technológia bluetooth, beacon, indikátor sily prijatého signálu

Introduction

Various technologies can be used for positioning and tracking purposes. The most accurate results can be achieved by combining them. On the other hand, each technology is suitable for sensing different features.

Bluetooth Low Energy (BLE) is a specification released in 2011 and is intended for energy efficient devices (Lu 2023). It operates in the 2.4 GHz frequency band just like classic Bluetooth (Said 2021). It represents a wireless technology that is characterized by low power consumption and is a standard of the Bluetooth 4.0 specification. Compared to previous Bluetooth standards, BLE was developed to simplify the communication over short distances of devices not requiring the transmission of large amounts of data. The aim was to provide a technology designed for monitoring and control applications where the volume of data transferred is low (Čabarkapa 2015).

The BLE data format contains 4 main pieces of information, namely UUID, Major, Minor and Tx-power. UUID (Universally Unique Identifier) is a 16-byte string that is used to distinguish different beacon devices. When beacons are placed in a commercial chain, the terminal is able to recognize the chain to which the devices belong. Major represents a 2-byte string used to determine the specific ownership of the devices. If a commercial chain has five beacon devices, all these devices have the same Major number. The Minor is characterized as a special identifier for each device or object. A beacon has a different Minor for one object. Tx-power is defined as the signal strength exactly 1 m from the device, which can be used to judge the wireless signal distance between the beacon device and the terminal. However, in an actual measurement application, the measured values of the beacon wireless signal range are not completely accurate. This is due to changes and fluctuations of the wireless signal or environmental factors and other characteristics (Ye 2020).

A BLE beacon is a fixed signal transmitter that transmits signals at regular intervals. Beacon messages allow the device to detect proximity to a specific location based on the received signal strength indicator (RSSI). Through this, site- specific information, advertisements and alerts can be provided to visitors (Čabarkapa 2015). A beacon is a wireless device that transmits signals, including location information, at regular intervals and sends user identifiers and RSSIs as Bluetooth signals. If the smartphone user is within the range of the beacon, the application installed on the smartphone receives the signal and sends the user information to the cloud server where the information is verified and the relevant information about the service provided is then sent to the user (Jung 2017).

Currently, BLE Beacons are used for a variety of purposes. They perform several functions that are constantly being improved. Their uses are varied and include, in particular:

- indoor positioning and navigation,
- tracking of persons or property,
- advertising or location-based messaging,
- security and automatic unlocking and locking of computers,
- triggering payment requests (Akpinar 2021).

The iBeacon protocol allows smartphones or other BLE devices to receive signals and execute commands (Huang 2023). The iBeacon protocol is currently used in order to provide location-based services. Based on BLE advertisements, devices within range are able to estimate or compute the location of people and entities inside buildings (Na 2021). iBeacon provides highly accurate location information and consumes low levels of energy compared to GPS, Wi-Fi or standard Bluetooth (Vy 2021).

The distance between the BLE Beacons and the smartphone can be detected based on the RSSI (Received Signal Strength Indication). This is the signal strength of the BLE Beacon as it can be seen on the receiving device, such as a smartphone. The signal strength is dependent on the distance and the transmit power value. RSSI is used to determine the approximate distance between the BLE Beacon and the receiving device based on another value that is defined by the BLE standard - the measured power. It is a constant that determines what the expected RSSI is at a distance of 1 m from the BLE Beacon. RSSI tends

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Young Science
ISSN 1339-3189

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to fluctuate due to external factors such as diffraction, absorption or interference that affect radio waves. The further the device is from the BLE Beacon, the more unstable the RSSI becomes (Anonym 2016).

Methodology

Experimental testing of an indoor localization system based on Bluetooth Low Energy Beacons supported by the iBeacon protocol was carried out. The experimental testing was based on the investigation of a person's movement along a predefined route. The aim of the testing was to assess the accuracy and reliability of a location system based on BLE beacons technology. The purpose of the testing was to verify the ability of the system to accurately track and record the movement of a person in a controlled environment along a predefined route in order to identify potential shortcomings of the technology.

The system under test consists of transmitting and receiving devices. The transmitting device was a Gigaset G-Tag Red beacon and the receiving device was a Raspberry Pi Zero 2 W microcomputer, whose power source was an external charger. For testing purposes, 1 transmitting device was used, which was operated by a person moving along a predefined route in the space, and 4 receiving devices, each device being placed in a corner of the room and installed at a height of 1.6 m. The localization system also included a Wi-Fi router in order to create an internet network through which the data from the receiving device was sent to a server. The receiving devices were stored in a plastic lockable cabinet, which also contained an external power supply to power it.

Fig. 1 – Receiving device and external power supply
Source: authors

The measurements were carried out in a room with an area of 3x5 meters, which was divided into 15 squares of 1x1 meter for better orientation in space and evaluation purposes. The room included doors and windows. In addition to better orientation in space, the squares also served

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Young Science
ISSN 1339-3189

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to realize movement, as the moving person holding the beacon stayed in the square for approximately 3 minutes, while the beacon was placed at a height of approximately 1.1 meters in the hand of the moving person.A scheme of the room division is shown in Fig. 2.

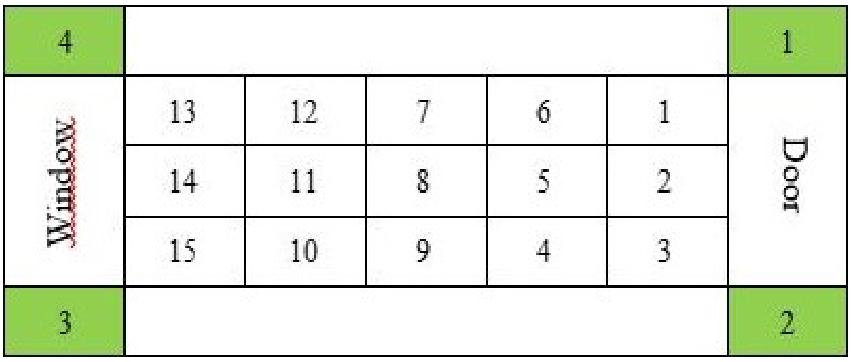

Fig. 2 – Room division scheme
Source: authors

Results

One of several simulations of movement on a checkerboard floor was selected. It is a movement along 6 selected points. A person's transitions along the selected points are shown in Fig. 3.

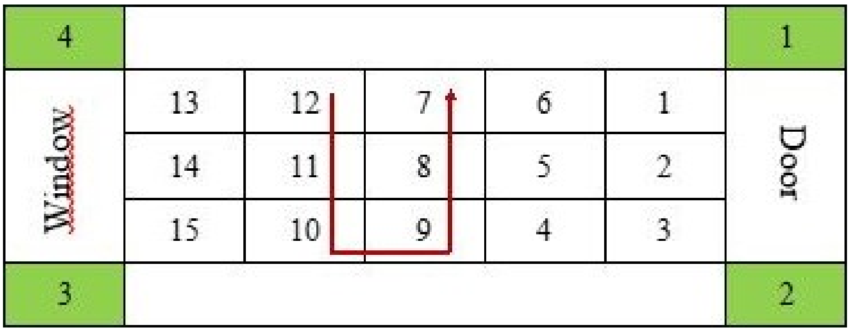

Fig. 3 – Scheme of movement of a person along the selected points
Source: authors

The RSSI values obtained from each transition point were processed by calculating the arithmetic mean and modus, which represents the most frequently occurring RSSI values recorded by a given receiving device.

Each transition point according to Fig. 3 was then divided into 4 squares. Each of the squares interprets the RSSI values recorded by each receiving device. A given color of RSSI values belongs to the same color code of the receiving device. The arithmetic mean (AVG), modus (MDS) and the real distance of the transmitting device from the receiving devices (VZD) at individual points in space are shown in Fig. 4.

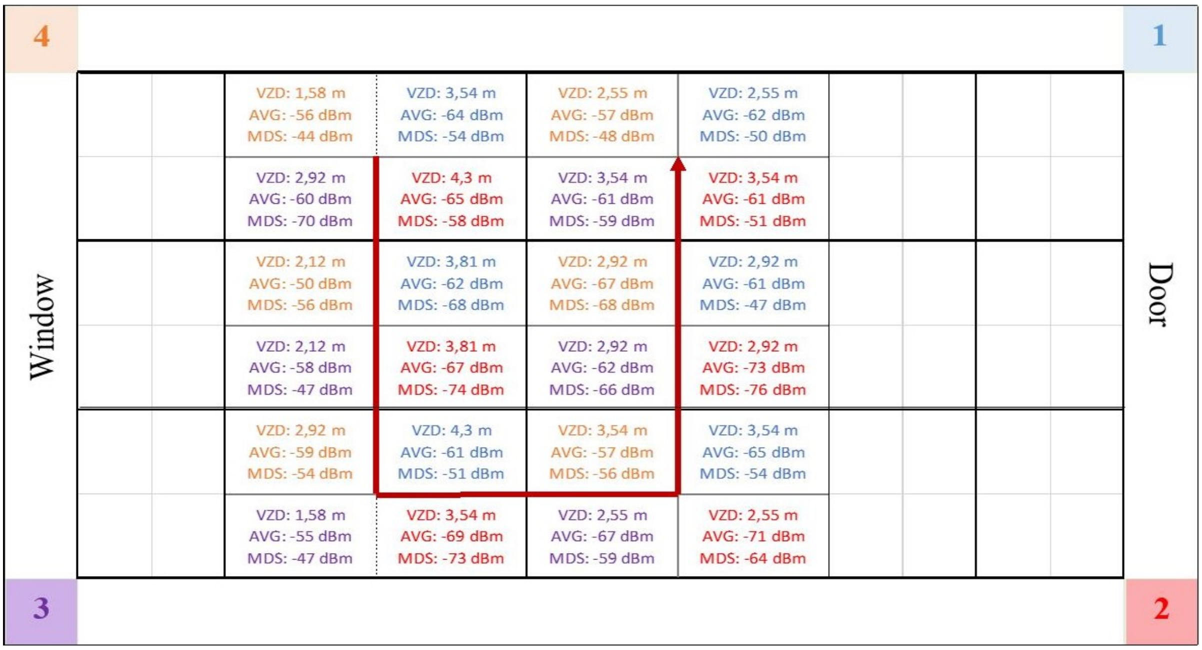

Fig. 4 – Interpretation of arithmetic mean, mode and real distance
Source: authors

Minus RSSI values for AVG and MDS determine how far the BLE Beacon chip is from the receiving device. These are unique values representing the radius of an imaginary circle created around the receiving device. If there was only one receiving device, it would not be possible to determine its location, as it could be anywhere on the mentioned circle. However, since there are 4 receiving devices, it is possible to determine the position of the beacon in the room by connecting the circles to each other.

1	2	3	4
VZD: 2,55 m AVG: -62 dBm MDS: -50 dBm	VZD: 2,55 m AVG: -71 dBm MDS: -64 dBm	VZD: 1,58 m AVG: -55 dBm MDS: -47 dBm	VZD: 1,58 m AVG: -56 dBm MDS: -44 dBm
VZD: 2,92 m AVG: -61 dBm MDS: -47 dBm	VZD: 2,92 m AVG: -73 dBm MDS: -76 dBm	VZD: 2,12 m AVG: -58 dBm MDS: -47 dBm	VZD: 2,12 m AVG: -50 dBm MDS: -56 dBm
VZD: 3,54 m AVG: -65 dBm MDS: -54 dBm	VZD: 3,54 m AVG: -69 dBm MDS: -73 dBm	VZD: 2,55 m AVG: -67 dBm MDS: -59 dBm	VZD: 2,55 m AVG: -57 dBm MDS: -48 dBm
VZD: 3,54 m AVG: -64 dBm MDS: -54 dBm	VZD: 3,54 m AVG: -61 dBm MDS: -51 dBm	VZD: 2,92 m AVG: -60 dBm MDS: -70 dBm	VZD: 2,92 m AVG: -67 dBm MDS: -68 dBm
VZD: 3,81 m AVG: -62 dBm MDS: -68 dBm	VZD: 3,81 m AVG: -67 dBm MDS: -74 dBm	VZD: 2,92 m AVG: -62 dBm MDS: -66 dBm	VZD: 2,92 m AVG: -59 dBm MDS: -54 dBm
VZD: 4,3 m AVG: -61 dBm MDS: -51 dBm	VZD: 4,3 m AVG: -65 dBm MDS: -58 dBm	VZD: 3,54 m AVG: -61 dBm MDS: -59 dBm	VZD: 3,54 m AVG: -57 dBm MDS: -56 dBm

Fig. 5 – Measured values of the receiving devices relative to the distance
Source: authors

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Discussion and conclusion

The article interprets the results of experimental testing of an indoor localization system based on BLE beacons in terms of investigating RSSI values when people move along a predefined route in a confined space. The person holding the transmitting device moved in the area along a predetermined route consisting of 6 marked points. RSSI values interpreting the quality of the received signal strength were evaluated by means of arithmetic mean and mode. The real distance of the transmitting device from the receiving devices was also determined.

Based on the experimental testing carried out, it can be concluded that the value of the modus (MDS) corresponds better with the distance. In the case of reflections of transmitted radio waves, the situation occurs that in a certain period of time significantly different values from the expected ones will be recorded, as a result of which a change in the average value may occur.

In Fig. 5, the measured values were arranged so that the columns listed the measured values of each receiving device and then arranged by distance. Based on this interpretation, it can be concluded that the value of the most frequent RSSI decreases with increasing distance. This phenomenon is best seen in the RSSI values when the beacon distance changes by 1 meter, which are shown in blue in Fig. 4.

For values of greater distance, the measured values were lower than expected. It is assumed that this situation occurred due to smaller room dimensions and larger distances between the transmitting and receiving equipment. This phenomenon has to be taken into account and the parameters have to be defined in the final setup of the system in a specific space to correct for these phenomena.

The conclusion of the experimental testing of a person's movement along a predefined route showed that a system based on BLE beacon technology and Raspberry Pi Zero 2 W provides an effective solution for location tracking under controlled conditions. The testing results confirmed that the Raspberry Pi Zero 2 W can effectively record and process the signals from the beacons, enabling accurate tracking of a person's route in a variety of environments. However, some limitations were identified, particularly in cases where signal interference can significantly affect the accuracy of localization.

This article has been recommended for publication in Young Science by
prof. Ing. Tomáš Loveček, PhD.

The article was supported by the project of the University of Žilina in Žilina APVV-20-0457: „Monitoring and tracking of movement and contact of persons in health care facilities".

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ISSN 1339-3189