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ДОПУСТИТИ ДО ЗАХИСТУ

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КВАЛІФІКАЦІЙНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

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Освітньо-професійна програма «Комп'ютерно-інтегровані технологічні процеси і виробництва»

Тема: Індивідуальна мобільна система навігації всередині приміщень

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Київ 2023

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«___» ______________ 2023

QUALIFICATION WORK

(EXPLANATORY NOTE)

GRADUATE OF EDUCATION AND QUALIFICATION LEVEL “BACHELOR”

Specialty 151 "Automation and computer-integrated technologies"

Educational and professional program "Computer-integrated technological processes and production"

Theme: Individual mobile indoor navigation system

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APPROVED

Head of Department

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«____» __________2023

TASK

For the student's thesis

Panasiuk Oleksii Oleksandrovych

1. Theme of project: “Individual mobile indoor navigation system”.
2. The term of the project: from May 10, 2023, until June 7, 2023
3. Output data to the project: radio navigation methods, object area, routing methods, indoor navigation methods.
4. Contents of the explanatory note: 1. Analysis of the current state of indoor navigation; 2. Problems of determining the location of a mobile device; 3. Theory of radio navigation; 4. Determine the position and route of the user in the building.
5. List of required illustrative material: tables, figures.
6. Planned schedule.

№	Task	Execution term	Execution mark
1.	Getting the task	01.04.2023 – 02.04.2023	Done
2.	Formation of the purpose and main objectives of the study	02.04.2023 – 14.04.2023	Done
3.	Analysis of existing methods	15.04.2023 – 30.04.2023	Done
4.	Theoretical consideration of problem solving	01.05.2023 – 05.05.2023	Done
5.	Writing a program for internal navigation	06.05.2023 – 25.05.2023	Done
6.	Preparation of an explanatory note	26.05.2023 – 03.06.2023	Done
7.	Preparation of presentation and handouts	04.06.2023 – 06.06.2023	Done

7. Date of task receiving: «_01__» ____april____ 2023.

Diploma thesis supervisor ________________ Mykola VASYLENKO

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Issued task accepted ______________ Oleksii PANASIUK

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Спеціальність: 151 «Автоматизація та комп'ютерно-інтегровані технології»

ЗАТВЕРЖДУЮ

Завідувач кафедри

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«___» __________2023

ЗАВДАННЯ

На виконання дипломної роботи

Панасюка Олексія Олександровича

1. Тема проекту: «Індивідуальна мобільна система навігації всередині приміщень».
2. Термін виконання роботи: з 10.05.2023р. по 07.06.2023р.
3. Вихідні дані роботи: методи радіонавігації, площа обєкту, методи маршрутизації, методи навігації в приміщенні.
4. Зміст пояснювальної записки: 1. Аналіз сучасного стану внутрішньої навігації; 2. Проблеми визначення місцезнаходження мобільного пристрою; 3. Теорія радіонавігації; 4. Визначення положення та маршруту користувача в будівлі.
5. Перелік обов'язкового графічного матеріалу: таблиці, рисунки.
6. Календарний план-графік.

№	Завдання	Термін виконання	Підпис керівника
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2.	Формування мети та основних завдань дослідження	02.04.2023 – 14.04.2023	Виконав
3.	Аналіз існуючих методів	15.04.2023 – 30.04.2023	Виконав
4.	Теоретичний розгляд вирішення проблеми	01.05.2023 – 05.05.2023	Виконав
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ABSTRACT

Explanatory note of the qualification work "Individual mobile indoor navigation system" 76 p., 7 figures, 2 tables, 10 sources.

The goal of this work is to enhance the ability to navigate inside large rooms using Wi-Fi transmitter technology. This will solve the problem of indoor orientation and reduce the time people spend searching for the right place.

The object of research is the process of creating a mobile application that provides and improves indoor navigation.

Research methods. The study uses such methods as indoor navigation, navigation using Wi-Fi transmitters, and visual presentation of results.

The subject of the study is approaches to creating an indoor navigation system.

Keywords: indoor navigation, radio navigation, trilateration, Wi-Fi positioning.

РЕФЕРАТ

Пояснювальна записка кваліфікаційної роботи «Індивідуальна мобільна система навігації всередині приміщень» 76 с., 7 рис., 2 табл, 10 джерел.

Метою цієї роботи є покращення можливості навігації у великих приміщеннях за допомогою технології Wi-Fi передавачів. Це дозволить вирішити проблему орієнтування в приміщенні та зменшити час, який люди витрачають на пошук потрібного місця.

Об'єктом дослідження є процес створення мобільного додатку, що забезпечує та покращує навігацію в приміщенні.

Методи дослідження. У дослідженні використовуються такі методи, як навігація в приміщенні, навігація за допомогою Wi-Fi передавачів, візуальне представлення результатів.

Предметом дослідження є підходи до створення системи внутрішньої навігації.

Ключові слова: навігація в приміщенні, радіотехнічна навігація, трилатерація, Wi-Fi – позиціонування.

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GLOSSARY

WPS - Wi-Fi positioning system

BLE - Bluetooth Low Energy

VLC - Visual Light Communication

UWB - Ultra-wideband

RSSI - Received Signal Strength Indication

DGPS - Differential Global Positioning

GINS - Global Inertial Navigation System

GLONASS - Global Navigation Satellite System

AI - artificial intelligence

INS - Inertial Navigation Systems

LEO - Low Earth Orbit

IoT - Internet of Things

INTRODUCTION

The relevance of this work is confirmed by the fact that the problem of indoor navigation, as well as the provision of services to visitors based on their location, is becoming increasingly important.

In today's world, people spend a significant part of their time inside various buildings, such as shopping malls, airports, universities, hotels, which have a complex structure that is difficult for an untrained person to navigate, so one of the main arguments for relevance is to improve the user experience by providing users with convenient and accurate route instructions inside buildings, helping them find the necessary locations, such as shops, restaurants, offices, restrooms, and others. This improves the overall user experience and encourages repeat visits.

An individualized mobile indoor navigation system also helps to achieve efficient use of building space. Thanks to the navigation system, passengers or visitors can be distributed along different routes, which prevents congestion and overcrowding in certain areas. This rationalizes the movement of people, ensures better flow and improves the overall logistics of the premises.

The smartphone navigation system plays an important role in improving indoor safety. The system can be integrated with security systems, such as fire and explosion detection systems, allowing for a quick and efficient response to dangerous situations. It can also provide information about evacuation routes and emergency exit locations, which facilitates quick evacuation and ensures the safety of all those present.

A customized mobile navigation system has the potential for advertising and marketing purposes. Thanks to the navigation system, it is possible to provide users with personalized advertising messages, promotions and offers that meet their needs and interests. This creates new opportunities for advertisers and sponsors who can effectively communicate with their target audience indoors.

Indoor navigation is becoming more and more popular due to its significant commercial prospects. It has already attracted the attention of such well-known market players as Apple, Google, Broadcom, Qualcomm, Sony, and others, and it is undoubtedly a promising area.

The goal of this work is to enhance the ability to navigate inside large rooms using Wi-Fi transmitter technology. This will solve the problem of indoor orientation and reduce the time people spend searching for the right place.

The object of research is the process of creating a mobile application that provides and improves indoor navigation.

The subject of the study is approaches to creating an indoor navigation system.

To achieve this goal, it is necessary to solve the following tasks:

- analyze and evaluate the effectiveness of existing indoor navigation methods;
- create a model for evaluating the effectiveness of indoor navigation and define standards for improving the development process;
- to develop an application for indoor navigation based on the chosen approach;
- to test the developed theoretical provisions, methods, algorithms and tools in practice.

Research methods. The study uses such methods as indoor navigation, navigation using Wi-Fi transmitters, and visual presentation of results.

Main scientific and technical results:

- Methods for indoor navigation using a Wi-Fi transmitter have been developed. Unlike existing analogues, these methods allow users to quickly navigate the environment and determine the exact location of the user, and then use this data to determine the fastest way to the desired location of the object;
- based on the developed method of indoor navigation, the method of using Wi-Fi transmitters to obtain accurate location of objects was further developed.

Publications. The results of theoretical research are presented in the scientific and practical conference "Flight".

CHAPTER 1. ANALYSIS OF THE CURRENT STATE OF INDOOR NAVIGATION

1.1 Description of the mobile indoor navigation system

Since GPS navigation does not work in buildings, when automatic positioning is required, another positioning technology is used. In this case, Wi-Fi or Bluetooth beacons are often used to create an "indoor GPS".

However, unlike GPS, they also allow you to determine the actual floor level. Most applications require an "indoor routing" function. This function is similar to navigation systems in cars, as it precisely guides people through the building with the help of an indoor navigation program and automatically determines their position.

A standard application is turn-by-turn navigation, which is an application used for airports, shopping malls, train stations, and museums. This type of app can have many other useful features [1].

Indoor navigation is also possible without automatic positioning - for example, when a digital building map is integrated into a digital signage system or a website. In this case, no location devices such as beacons or Wi-Fi are required.

With automatic positioning, indoor navigation is a popular client application. This means that the position is determined directly on the user's smartphone, so you need to create a program that can perform these tasks. As a rule, beacons or Wi-Fi are used to find your place. In addition, a feedback channel is available that can be used to send push notifications. A server-based approach is also possible, but you may encounter technical problems.

Moving around indoors is similar to providing customers with a location map on their phones. This technology can power smart buildings, which improves navigation and reduces the time it takes to find items. It also allows business owners to provide location-based content and advertising.

To help visitors navigate buildings, they need to use internal navigation. Here are some examples of how to use internal navigation:

Shopping centers: Indoor navigation helps shoppers navigate large shopping centers, find the right stores, sections, promotional offers, and get information about products and services.

Airports: Indoor navigation is extremely useful for passengers who are looking for their gate, boarding a flight, or looking for various facilities in the airport, such as restaurants, shops, currency exchangers, etc.

Medical facilities: Indoor navigation helps patients and visitors to hospitals and clinics find the right wards, doctors' offices, laboratories, pharmacies, and other facilities.

University campuses: Indoor navigation helps students and teachers navigate complex university complexes, find classrooms, libraries, laboratories, sports facilities, and other important locations.

Hotels and resorts: Indoor navigation helps hotel guests find their rooms, restaurants, swimming pools, fitness centers, meeting rooms, and other hotel services and amenities.

Museums and exhibition centers: Indoor navigation helps visitors navigate inside museums and exhibition centers, find exhibits, exhibitions, information points, and other objects [2].

1.2 Benefits of indoor navigation

Customers are the main beneficiaries of all the advances in indoor navigation, as its original goals were to attract new customers and provide them with a more personalized shopping experience [3].

Indoor positioning and navigation systems offer customers the following key benefits:

- Easy to find certain things. Loyalty programs installed on shoppers' phones can get them to the right shelf faster and help them check off more items on their shopping list with advanced store navigation systems. Shoppers can immediately visit the merchant's website to order an item if it is out of stock.
- It is easy and quick to find the store you need. Modern shopping centers and malls are huge, with hundreds of stores and several floors. In fact, traditional maps are not always easy to understand and are sometimes misleading due to the fact that GPS navigation

sometimes works poorly or does not work at all. Today's shoppers appreciate a simple app that guides you through food courts, drive-throughs, and mazes of aisles straight to the point of purchase.

- Advertising. Indoor positioning systems can send promotional messages to shoppers passing by to let them know about exclusive prices or new products that are currently available. This way, customers can take advantage of opportunities they might otherwise miss.

In addition to the features that customers expect to find only online, mall navigators add interactivity to the traditional offline shopping experience. Just like a special offer banner that pops up on your screen while you're shopping online, or a quick discount notification you might receive on your smartphone while you're looking at new sneakers in a men's shoe store can tip the balance and lead to a positive outcome [4].

An indoor positioning system is of great benefit to the owners of the premises. Wayfinding systems can increase sales and generate a great deal of marketing data if they are well designed, configured, and implemented. Here are some of the biggest direct benefits of using an indoor positioning system in retail:

- Expanding visitor data The indoor positioning system, unlike traditional sensors, collects a large amount of data, including the number of visitors, individual and group visitors, average time spent in the store, departments visited, time spent in each department, etc.
- Building location analytics Management can gain valuable insights into customer behavior by knowing where people go and how long they spend there. This allows them to optimize the location of stores and other facilities, as well as attract more customers to unpopular areas.
- Premises optimization. Indoor positioning data helps to evaluate the impact of placement changes, rearrangements, advertising campaigns, and other measures aimed at increasing conversions and sales.

Thus, indoor positioning and wayfinding systems have a positive impact on business. They contribute to the creation of a large amount of extremely important data that is used for marketing purposes, increasing traffic and creating a constant flow of visitors[5].

1.3 Technologies and their types for internal navigation

The internal positioning system uses the same transmitter-receiver principle as the well-known Global Positioning System. GPS is a positioning system using satellites around the world. It requires a free "line of sight" to several satellites - theoretically three, but in practice from six to twelve. During signal propagation, GPS receivers can determine their own position and speed. This location information, in combination with geo-information such as topography, streets, air or sea maps, can be used to direct the user to a selected location or to create a route according to desired criteria.

The transmitter transmits radio signals to the receiver. The receiver interprets these signals and determines where they are located within a particular topographic image. This is based on the principles of trilateration and triangulation. Radio-based indoor positioning and navigation systems also contain the three elements mentioned above: transmitter, receiver, and environmental information. Indoor navigation and search always require appropriate applications.

There are different indoor positioning technologies such as Wi-Fi, Bluetooth Low Energy (BLE), Near Field Communication (NFC), Radio Frequency Identification (RFID), Ultra Wideband (UWB), etc. Compatibility, accuracy, cost, and effort differ significantly.

1.3.1 Wi-Fi positioning system technology

Wi-Fi is a technology that uses radio waves to allow people to connect to a network. To establish a wireless connection, a wireless adapter is used to create a local wireless network near a wireless router. The router connects to the network, allowing users to access Internet services. Setting up a Wi-Fi network allows you to wirelessly connect to devices and emit frequencies from 2.4 GHz to 5 GHz, depending on the amount of data passing through the network.

Skyhook Wireless coined the term WPS to describe its Wi-Fi positioning system. Apple, Google, and many phone manufacturers and phone operators have created extremely large databases of Wi-Fi hotspots by connecting Wi-Fi hotspots to the GPS location of a smart device.

Any contract with a mobile operator provides for anonymous location of the user. Most smartphones allow you to disable location services. Google provides an option to release the network shape stored in the WPS database. In order for the WiFi network to be displayed, you need to add the "_nomap" extension to the network name. When combined with triangulation of mobile operator repeaters and GPS, WPS can provide accurate and reliable user position data in a wide range of conditions, including passages between tall buildings and enclosed areas where GPS signals may be weak or intermittent.

The disadvantages of WPS technology are as follows: WPS does not work if the user is out of range of Wi-Fi signals, and the Wi-Fi access point database must be constantly updated.

Wi-Fi can also be used for BLE transmitters, but it requires an external power supply, more expensive hardware, and higher installation costs. Although the smart device does not necessarily need to be connected to a Wi-Fi network, it must be activated. The signal is stronger than that of BLE technology, and it can cover longer distances with an accuracy of 5-15 meters.

There are various positioning methods that use Wi-Fi technology. Triangulation is one of them.

Triangulation uses the intersection of three circles of Wi-Fi access points to determine the exact position of the user. Triangulation collects the signal strength of all Wi-Fi access points that are currently available. The signal strength is used to determine the distance of the user from specific access points, which gives the exact position. The process is neither complicated nor difficult to perform. The dynamic positioning method is also called triangulation.

The intensity of the received RSSI signal and the "fingerprinting" method are an additional method of positioning using a wireless access network. In addition, the MAC address of the device is used. The application on the user's smart device determines the current position of the user using the fingerprint method and the intensity of the received signal.

The fingerprinting method consists of two phases: offline and online.

During the offline phase, an RSS19 database with the corresponding location coordinates is prepared. The signal strength data is collected in the database after being collected from several locations. This is the most important step that determines the accuracy of the search.

In the online stage, the user sends a query for the RSS data to the database, which means that the known coordinates are compared with the unknown coordinates and the most accurate location is determined. Different algorithms are used to find the relevant records in the dynamic RSS database. Creating and maintaining an RSS fingerprint database is the most challenging task of the method. To add, exclude, or delete fingerprints, the database needs to be updated. If another sensor, such as a camera, is installed in the system, the problem can be easily solved.

1.3.2 Bluetooth Low Energy technology

Bluetooth technology is a wireless communication standard for exchanging data at close range. It was first developed by Ericsson in 1994. In 1998, Ericsson, Nokia, Intel, IBM, and Toshiba created the Bluetooth Special Interest Group (SIG). Licensing of Bluetooth technology, proper implementation and improvement of standards are the responsibilities of the competent authority.

The main characteristics of the technology are inexpensive devices, reliability, low power consumption, short range and the ability to be used worldwide. To maintain a transmission speed of 1 Mbps, Bluetooth uses the unlicensed frequency band 2.4 to 2.458 GHz, i.e., it uses scientific, medical and industrial areas where the frequency is harmonized worldwide. In addition, Bluetooth can be used for radio communication with other systems. Different device manufacturers are not compatible with each other, but packet and channel switching is allowed.

In mid-2010, the Bluetooth SIG introduced the Bluetooth 4.0 specification, which included low energy, high-speed, and classic Bluetooth protocols.

Bluetooth Low Energy (BLE) is characterized by very small size, low cost, low power consumption with the possibility of several years of operation on a small power source and compatibility with mobile devices, tablets and computers.

Bluetooth 4.0 offers two modes of operation: single mode and dual mode to install BLE technology on a device. Dual-mode operation allows controllers to integrate BLE functions, but single-mode operation does not allow controllers to integrate BLE functions. Device manufacturers can use both modes. However, devices with single-mode operation cannot interact with devices that use the traditional Bluetooth protocol.

Today, most mobile devices support both Bluetooth and Bluetooth Low Energy, meaning they contain a dual-mode Bluetooth microcontroller.

BLE signals are transmitted from transmitters that run on batteries. Most devices such as smartphones, tablets, and smartwatches support this technology. It uses cheap, small location devices. These devices last for a long time and do not need an external power source. The device can determine the location after detecting the transmitter signal and estimating the distance to it.

Using Bluetooth Low Energy technology, transmitters can inform devices that they are present. Devices in the vicinity, such as tablets and mobile devices, can subscribe to transmitter notifications and receive different types of content, such as images, text, and URLs. At the same time, transmitters can be used for contactless payments in a similar way to NFC.

The transmitters have an accuracy of 2-3 meters and are resistant to dust and water in accordance with the IP67 standard. The lifespan of the transmitter is estimated at 6-8 years. To use BLE technology, you need to turn on Bluetooth or BLE.

The BLE transmitter has the ability to send notifications to the user when the user is in a certain location.

1.3.3 Visual Light Communication technology

Visual Light Communication is a wireless technology that works with LEDs. The term Li-Fi is derived from Wi-Fi technology. It can be used as a stand-alone device or as a supplement to radio communications such as Wi-Fi mobile communications or. VLC switches the LED to a high frequency from the on to the off state and vice versa.

The LED transmits a flashing light pattern to the receiver, i.e. the smartphone camera. The pattern is transmitted to the server in an encrypted form. The encrypted shape of the pattern is compared with the shape on the map on the server. When the same encrypted shape of the pattern is found on the map, the system believes that the user is under the LED.

The disadvantage of VLC technology is that the user's camera must have visual contact with the LED during operation. Unlike BLE, which does not require visual contact, the device does not receive a notification. The location can be determined by VLC very accurately, even up to 4 centimeters.

1.3.4. Geomagnetic technology

Magnetic field detection can also be used for indoor positioning using the compass sensor. The smart device uses the so-called "fingerprinting" method to create a magnetic map of a specific location and then use this map to find rooms within the room. This method is only effective when the magnetic fields in the room are stable. Only IndoorAtlas currently uses this technology. The material from which buildings are made distorts the magnetic fields. The imprint has more uniqueness when there is more metal in the area. No additional equipment needs to be installed for such a system. To collect data for magnetic positioning, it is necessary to walk through the room. The magnetic footprints of the area are linked to the building plan on the cloud system. Covering 25,000 square meters with an accuracy of 1-2 meters takes hours. In addition, non-technical staff and any user was allowed to create a magnetic footprint using only instructions and smart phones.

1.3.5. Ultra-wideband technology

Often, very precise localization is required to track rooms in industrial environments. For this purpose, we offer solutions based on short-range ultra-wideband radio technology.

Although it does not support consumer standards such as Wi-Fi and Bluetooth Low Energy, it has an accuracy of over 30 cm.

Indoor UWB positioning has its advantages: accuracy of 10 to 30 cm, which is better than using Wi-Fi or beacons. Very short delay time. We can accurately measure the height difference. Nevertheless, this technique is a specific method that requires appropriate parts, so it is mostly used for specific industry applications.

Ultra wideband is a radio technology that is short range and is used for indoor positioning. Positioning is done using a transit time methodology instead of measuring signal strength, unlike Wi-Fi and Bluetooth, which require less power.

This method is used to measure the frequency of light transmission between an object and multiple receivers. Anchors are used for localized infosoft. At least three receivers are needed to accurately localize an object. In addition, there must be a line of sight between the receiver and the transmitter.

For example, an object to be tracked is equipped with a small tag that runs on battery power or is picked up by a forklift. It sends data to the Locator nodes, including an identifier and a time stamp.

Each node has its own position assigned to it in the infrastructure and can determine the distance of the asset using the light's operating time. Positioning accuracy of 5-30 cm is achieved by combining data from three or more locator nodes.

1.4 Analysis of indoor navigation characteristics

The type of customer, maintenance, battery life, location accuracy, installation costs, security, and mapping method are the starting point for choosing technologies for implementing an indoor navigation system.

The exact location indicates at what distances an object can be located. The use of the positioning system determines the importance of the category. For example, an accuracy of 1 or 10 meters should not be a problem if the user is to be directed to the airport exit or to the dentist's office. Increased accuracy is required when a person needs to be oriented to a specific product or group of products.

In terms of operating time, this is the case with BLE transmitters, as they are the only ones that use a battery. The service life of the transmitter depends on the model, settings, and battery type, and can exceed a year.

The source does not provide information on the cost and lifespan of LED bulbs with VLC technology. The estimated hours of operation and wattage of the bulb will determine the lifespan. When the bulb is on 24 hours a day and has 50,000 hours of operation, its life expectancy can be more than 5 years.

Maintenance can only be analyzed for BLE, Wi-Fi, and VLC technologies because they are hardware components. Hardware components are not used in geomagnetic technologies, so studying maintenance can be more difficult.

BLE technology requires constant calibration depending on changes in the monitored area and skilled installers. Maintenance is easier if the management of transmitters is concentrated in one center.

Given that Wi-Fi infrastructure is often already in place, positioning Wi-Fi technology in a building becomes easier. Adapting to changes in the infrastructure and environment is also part of ongoing maintenance. This can include software or hardware issues, system upgrades, or enabling or disabling the access point if the router is managed by a third party, such as a store owner in a shopping center.

The costs and maintenance of VLC LED bulbs are not significant. When a bulb reaches the end of its service life, it is replaced with a new one.

Hardware components can fail or be stolen, so they need to be replaced. Compared to light bulbs, Wi-Fi and BLE transmitters have a better level of security.

The user's location data is sensitive data and if it is accessible or insufficiently protected, it can lead to problems. The security level of a system can be described through the technical specifications.

Generally, customers can be safely located in a room with BLE transmitters or through a Wi-Fi system. This type of system determines the user's position directly on the user's smart device without the need for additional communication with the server [4]. Thus, no data is transmitted. BLE transmitters cannot store personal data of users. They only contain important data, such as the device ID, to access and manage it.

The server uses RSSI, BLE transmitter UID, timestamp, and smart device UID for anonymous tracking programs. In addition, you get the MAC address of the smart device. If the user is registered anonymously, no information about him or her will be transmitted.

The "rolling ID" method protects BLE transmitters from third parties. Only the transmitter operator can decode the transmitter. Due to the change of the transmitter ID, the administrator must access the transmitter through the system administration interface.

Although the source claims that LED light bulbs with VLC technology are very secure, there is no example or detailed description. Companies respect user privacy, so its system is designed in such a way that no user data is collected or stored. Users of the programs log in without registration.

Installation costs. Since the device does not require installation due to magnetic technology, no installation is required.

If all of your current luminaires were to be replaced, VLC technology could result in high costs. Since there is a need to install the luminaires, the initial installation is not expensive. To estimate the installation costs, the price of a VLC LED bulb should be compared to the price of a conventional bulb.

Installing Wi-Fi is not expensive if one intends to use the existing infrastructure or some part of it. Even so, if access points are being introduced for this purpose alone, device and installation costs will be factored in as installation costs.

BLE transmitters cost between $10 and $20 per unit, depending on the settings, power, and model. While the unit price is not high, the location of the transmitter affects the IPS modeling, so the total installation cost can be high due to quantity.

Mapping of a given territory for the use of IPS. For Wi-Fi and VLC technologies, it is necessary to create a map of the system installation site, as well as calibrate the system if necessary [5]. Similar procedures and programs are used to manage all devices in BLE technology.

As for magnetic technologies, users can collect magnetic field data themselves and then transmit it to the IPS manufacturer. From that point on, the data is processed and available for use. The user can make any changes in the same way. Since this method of mapping an area does not require field work by skilled workers, it is not expensive. Waze uses a similar strategy.

Android and iOS users are the types of customers. The aforementioned system is limited to Android users, other technologies other than Wi-Fi based IPS systems can work with both types of clients. Since 2011, iOS devices have not supported positioning using Wi-Fi technology at the client. In the presentation of iOS 8, Apple introduced an integrated indoor location service.

Devices with Wi-Fi and iBeacon technologies can use motion sensors to determine where a person is in the room [5]. In addition, the technology will be used in public places, where Apple will be able to work with building owners to provide services. Android users will not be able to use the service.

Blue Dot Navigation When navigating a room, a blue dot is visible on the smartphone screen that constantly tracks the user's position. The blue dot changes depending on where the user is moving. When the dot on the screen moves with the user, it is called a "blue dot".

With certain algorithms and a densely distributed BLE transmitter, BLE technology can provide real-time monitoring. If there are not enough BLE transmitters in the building, blue dots are not possible. The blue dot experience is usually achieved in combination with other BLE technologies. Although it is limited, there is such a solution. The Estimote indoor positioning system shows the approximate position of the user in space. The center of each wall should contain Estimote beacons [5]. By walking near the beacons, the user can map the area and adjust the beacons. Once the process is complete, the user's location is automatically saved to the Estimote Cloud. The user can see their location in real time in this space using their SDK.Signal sensitivity. BLE technology when used for IPS is sensitive to changing radio conditions. The mere presence of people in the room can dramatically change the perception of the signal in different positions in the room. For this reason, in order to obtain good localization and signal perception when installing beacons, whenever possible, a line of sight is sought between the receiver and the beacon, usually by placing the beacons above head height.

Surfaces such as metal and glass can interfere with Bluetooth signals. You can use additional beacons to combat indoor interference. The Wi-Fi signal can also be blocked by consumer electronics, Bluetooth devices, physical barriers, or people.

The internal magnetic field contains location information, but the hard/soft iron effect, handshake, and electronic noise affect this information. In magnetic field-based localization systems, these interferences reduce the accuracy of location fingerprints [2].

According to the sensitivity of VLC technology, any obstacle that hinders the visual visibility of the LED light directly affects the operation of the internal positioning technology.

1.5 Conclusions to the chapter

It is difficult to determine which technology is the standard because the concept of internal navigation is new. In this section, I have analyzed whether indoor navigation is needed, examples of its use, and types of technology.

The results show that none of the technologies studied provides the best results for each of the evaluated characteristics; however, Wi-Fi technology was the best because it shows the best results for each specific case.

When implementing an indoor navigation system, a company should choose a technology based on the benefits of the system, the type of building it will be used in, and the budget.

There is still no single standard for indoor navigation technologies. Finally, a standard can be created using one of the existing technologies, a new technology, or a combination of these technologies.

CHAPTER 2. PROBLEMS OF DETERMINING THE LOCATION OF A MOBILE DEVICE

2.1 Internal positioning system

An indoor positioning system (IPS) is a system that includes a network of connected devices for wirelessly determining the position of objects and people inside buildings and partially enclosed areas. [5]

2.1.1 Internal positioning features

There is a basic question: "Why do they separate outdoor and indoor navigation systems?" Most positioning systems can work both indoors and outdoors, at least in theory. However, these two environments are very different, which explains the difference in performance. Indoor environments are difficult for position determination for several reasons:

- significant lengthening of the signal path due to reflections from walls and fittings;
- indirect visibility conditions;
- high degree of shadowing and signal scattering due to higher density of interference;
- rapid spatial changes due to the presence of people and the opening of doors;
- the need for high precision.

Nevertheless, there are some simplifications:

- small coverage areas;
- little weather exposure, low temperature, and slow air circulation;
- stable geometric constraints associated with the orthogonality of the walls and the presence of surfaces close to planes;
- access to infrastructure, such as the power grid and the Internet;

- lower process dynamics due to slow walking.

2.1.2 Basic principles of position determination

Positioning technology refers to building navigation systems that include methods for determining and estimating the position of nodes. There are many algorithms for obtaining distance and proximity information that are based on signal measurement and signal characteristics. Such algorithms calculate the real position of the target object after some characteristics of the signals, such as distances and angles, are transformed. Thus, the user can find out where he or she is during navigation [6].

Most of the components of positioning technologies, algorithms and methods are implemented outdoors, so they are not new. On the other hand, their behavior indoors is significantly different.

Signal properties and positioning algorithms are the two components that are used to determine the user's position. Signal properties are geometric parameters that consist of metrics such as angle, distance, and signal strength that can be used to determine the position of an object using mathematical calculations. The angle of arrival (AOA), time of arrival (TOA), difference in time of arrival (DTOA), and received signal strength indication (RSSI) are the main methods of measuring a signal.

In the AOA method, the angle and distance are calculated relative to two or more reference points by intersecting the guide lines. Figure 2.1 shows the process.

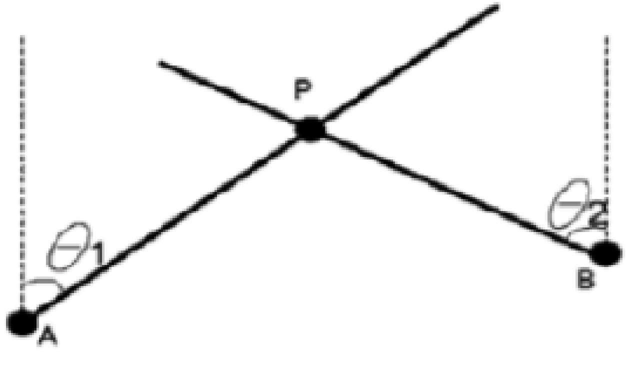

Fig. 2.1 - The angle of arrival method

Angle and distance are used to determine and estimate the position of the transmitter. This data can be used for positioning and navigation. In real life, the hardware is usually complex and expensive.

While AOA measurement is based on angles, TOA is based on distances, also called TOF, because it tracks the time it takes for a signal to arrive at the receiver from a fixed transmitter, which also serves as a reference point. TOF, on the other hand, is the time it takes for a signal to be transmitted from a mobile transmitter to a fixed receiver. Because the time is the same, these methods are synonymous. The only difference is what you consider a reference point.

TOA uses the entire arrival time, not the time difference between departure and arrival. While the method offers high accuracy, it is dependent on the complexity of the devices. The TDOA method is designed to eliminate this hardware complexity. The essence of the TOA method is shown in Figure 2.2.

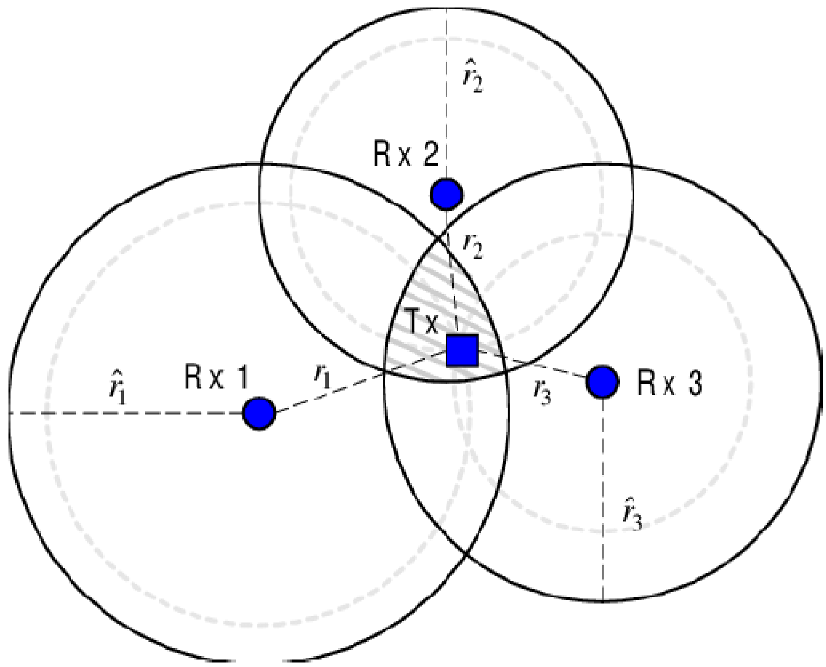

Fig. 2.2 - Arrival time method

The TDOA method, like TOA, is based on distance. Using the difference in signal propagation time to different reference points or sensors, it determines the relative position of the mobile transmitter. In other words, TDOA estimates the deviation of TOA from two or more sensors. This eliminates the need to know when a signal was sent. In addition, TDOA is highly accurate. Figure 2.3 illustrates the time of arrival difference method [6].

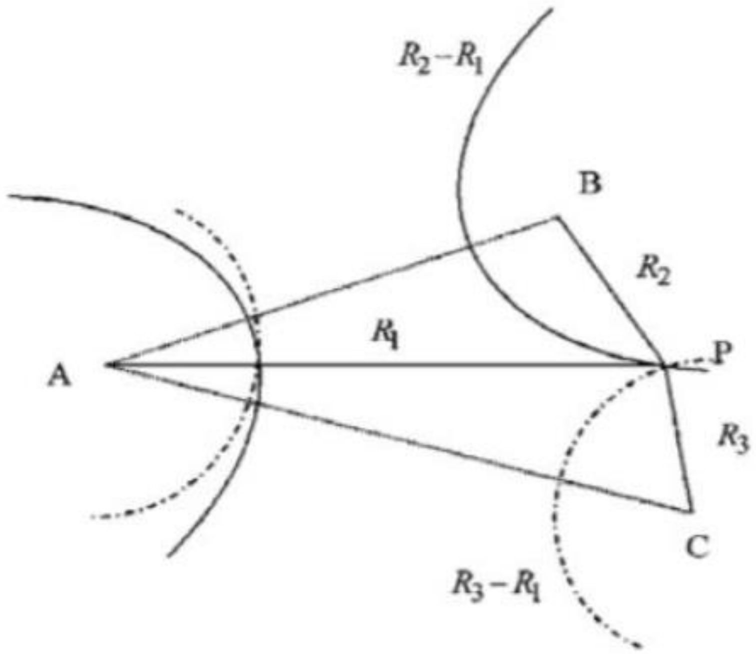

Fig. 2.3 - Arrival time difference method

Received signal strength, unlike distance and angle metrics, measures the strength of the received signal present in the radio infrastructure. This method can be used to estimate the distance between mobile devices. In other words, the RSSI method uses signal attenuation to determine the strength of the signal, which is reduced due to losses along its path. A higher RSSI means a closer transmitter and better signal quality. However, it is difficult to maintain a straight line of sight indoors, so positioning based on RSSI can be inaccurate due to shadowing and reflection.

Let's summarize by comparing the characteristics of the signals described in Table 2.1.

Table 2.1. Comparison of signal characteristics

Property of the signal	Measurement metric	Advantages	Disadvantages
Angle of arrival	Corner	Room-level accuracy	Complexity, high cost and low

			accuracy over wide coverage
Time of arrival	Distance	High accuracy	Complexity, price
Arrival time difference	Distance	High accuracy	Price
Indication of the received signal strength	Signal strength	Low cost	Average accuracy

Thus, signal properties are critical for determining the position, which is necessary for further computations. Due to the fact that the choice of the main property affects the final performance of the positioning system, it is a responsible one.

Positioning algorithms calculate the position of a target object. In other words, these algorithms calculate the position and transfer signal properties to different angles and distances. For example, the algorithm determines the position of an object when the distances between the reference points and the object have already been estimated.

The accuracy of measuring a signal property determines the accuracy of position information. Therefore, positioning algorithms have advantages and disadvantages, so using several types of algorithms increases the performance and accuracy of positioning. Thus, it is possible to use the direction, distance, or proximity information obtained through signal measurements to determine the position. But triangulation, trilateration, proximity, and scene analysis are the main algorithmic techniques for positioning. Positioning algorithms suitable for this purpose use different signal properties.

Triangulation, also known as angulation, estimates the position of an object by calculating angular measurements relative to two known reference points. In other words, the location of an object is the intersection of two guide lines. AOA is used to determine the distance between fixed points or guide lines.

In trilateration, the distances to three known points are used to determine the position. Multilateration works in the same way, but it receives information from four or more points. This method was used for the global positioning system GPS.

The proximity algorithm provides only a small amount of position information, unlike triangulation and trilateration. Consider a network of antennas with known positions as an example. The mobile device selects the strongest signal from the closest antenna. The RSSI, which estimates the distance between the antenna and the smartphone, allows you to determine the position of the device.

Scene evaluation algorithms are independent of angles and distances. Scene analysis collects information about scene features and compares it to one or more databases. Due to the fact that the collected information is different from others in the scene, it is also called a "fingerprint". The previously recorded database of signal strength in the coverage area is used in the fingerprinting method. Thus, we get more accuracy than methods of estimating signal propagation. But the data collection process requires a lot of time and effort to create signal strength maps for each Wi-Fi access point. Thus, the fingerprint method is expensive, complex, and slow.

Table 2.2. Comparison of positioning algorithms

Algorithm	Signal property	Advantages	Disadvantages
Triangulation	AOA	Simple, cheap, accurate within one room	Over a large area, coverage becomes expensive and complicated
Trilateration	TOA, TDOA	Precise	Complex, expensive
Proximity	RSSI	Simple	Often low accuracy, expensive
Scene analysis	RSSI	Does not require additional devices	Medium accuracy, may take a long

			time to create a coverage map

Determining the user's current position is the most important and complex part of internal navigation.

2.2 Analysis of existing software systems

Recently, position detection tasks have been limited to robotics. Algorithms were used during transportation and testing at work. It is now clear that portable navigation systems can bring many benefits to people. Thus, new hardware and software are being actively developed to solve specific problems.

Let's take a look at existing indoor positioning software systems by analyzing the search results for "indoor navigation".

2.2.1 Systems of specialized devices

InfSoft, a German company, is the first company to provide positioning services. Siemens, Swiss Federal Railways, Roche and Frankfurt Airport are among its most important customers. It is rated as a market leader.

Technologies include Wi-Fi, Bluetooth Low Energy, Ultra Wideband and RFID. It offers a device that can combine all of these sensors, meaning it is a versatile hardware unit for network deployment used for indoor navigation. In addition, the infSoft LocAware program is available, which means location awareness. The main modules are:

- search and diagnostics;
- real-time analytics and tracking;
- administering devices on the network;
- organization of teamwork on the network;
- tools for editing maps and diagrams.

Sonarax offers a new method of indoor navigation based on ultrasound. It uses sound waves that the human ear cannot hear, but which device microphones can still recognize. The product is just beginning to develop. Ultrasonic communication can be useful for many purposes other than navigation. Demonstrations of device interaction are available to the general public.

Indoo.rs, an Austrian company, was bought by geoservices giant Esri and is now part of ArcGis Indoors. Bluetooth Low Energy technology is the core technology. Their updated app includes analytics and adaptive map calibration for SLAM Crowd Engine users.

IndoorAtlas is another player in the market that aims to combine almost all existing positioning technologies into one product. Currently, it supports geomagnetic, inertial, GPS, Wi-Fi, and beacon positioning. According to the company, the accuracy of pedestrian movement is from 1 to 4 meters. The main features include wayfinding, object tagging, cross-platform compatibility, recognition of the current floor and changes, and contextual notifications to users.

Thus, we see that positioning based on wireless beacons emitting a signal is very common. Many companies create SDKs, or software development kits, for mobile applications.

2.3 Conclusions to the chapter

Thus, the theoretical foundations of indoor navigation systems are discussed in this section. There are existing options for commercial navigation in buildings, as well as methods for organizing such systems.

It can be assumed that today most mature companies use methods that require the placement of infrastructure, i.e. some devices. However, the benefits gained often outweigh the implementation and operating costs[7].

CHAPRET 3 THEORY OF RADIO NAVIGATION

3.1 Definition of radio navigation

Radio navigation is a set of methods and technologies that use radio signals to determine the location, orientation and navigation of objects in space. It is based on the use of radio waves propagating in the electromagnetic spectrum to transmit and receive signals between navigation receivers and transmitters.

Radio navigation is widely used in a variety of industries, including aviation, maritime transport, automotive, geodesy, telecommunications, and some military applications. Due to its efficiency and accuracy, radio navigation allows you to determine the location of objects with high precision, even in hard-to-reach or confined spaces.

The basic principles of radio navigation include the use of signals propagated by radio waves, calculation of the time of arrival of signals to the receiver, measurement of signals from different sources and their subsequent analysis. Methods such as trilateration, differential global positioning, and others are used to determine the coordinates of an object's location.

Radio navigation provides many advantages, such as high accuracy of location determination, wide coverage of the territory, the ability to work in various conditions, including poor visibility, night time, and weather conditions. It allows you to navigate objects with an accuracy of up to kilometers, which is critical in many areas of activity, including aviation and maritime transport.

However, radio navigation also has its limitations and challenges. It can be subject to interference, interference, and signal distortion, which can affect the accuracy and reliability of location determination. In addition, it requires the availability of appropriate infrastructure, such as radio stations, satellite systems, and transmitter networks, which can be costly and time-consuming.

3.2 Basic principles of radio navigation

The basic principles of radio navigation are based on the use of radio signals and their interaction with objects or systems in space. Here are some of the basic principles of radio navigation:

1. Distance determination: One of the basic principles of radio navigation is to measure the delay time of a radio signal sent from a transmitter and returned to a receiver. Using the speed of radio wave propagation, the distance between the transmitter and receiver can be calculated.

2. Trilateration: This principle is based on measuring the distance from an object to three or more known points or transmitters. Using these measurements, you can determine the exact location of an object by intersecting spheres or hyperbolas in three-dimensional space.

3. Doppler effect: Radio waves that are reflected or scattered from moving objects undergo a change in frequency. This effect is used to determine the speed of a moving object or to help pinpoint its location.

4. Radio pulse navigation: This principle uses the sending of short radio signals or pulses, which are then reflected from objects and returned to the receiver. The delay time between sending and receiving the pulse is used to determine the distance to the object.

5. Signals using satellites: Global navigation systems, such as GPS, GLONASS, or Galileo, use satellite signals to determine the location of an object. Receivers receive signals from different satellites and use the trilateration principle to determine the exact location.

These principles are the basis for the development of various radio navigation systems and help determine the location, path, speed and orientation of objects in space.

3.2.1 Using radio waves to determine location and orientation

The use of radio waves to determine location and orientation is one of the key aspects of radio navigation. This technology is based on the transmission and reception of radio signals between transmitters and receivers, which allows you to determine the position of objects in space.

The main methods of using radio waves to determine location and orientation include:

Trilateration: This method is based on measuring the distances between an object and three or more known radio signal transmitters. With the knowledge of the distances and the geometry of the system, the location of the object can be determined.

Multilateration: This method is used to determine the location by measuring the time of reception of signals from multiple transmitters. The signal path from each transmitter is calculated taking into account the time delays, and then the location of the object is determined.

Radio compasses: Radio compasses use radio signals to determine the orientation of an object. They rely on receiving signals from known directions and determining azimuth to determine direction of travel or orientation.

Other methods: In addition to the methods mentioned above, there are other radio-based approaches to location, such as radar systems, satellite navigation, and other specialized technologies.

The use of radio waves for location and orientation has wide applications in many areas, including aviation, navigation, automotive, logistics, military and civilian navigation, tourism, medicine, and many others. It allows you to accurately determine the location of objects, ensures safety, improves efficiency and contributes to convenience in various situations where it is important to know the position in space.

3.2.2 Trilateral navigation method

The trilateration method of navigation is one of the main methods of determining the location of an object based on measuring the distances between it and three or more known points in space. This method is based on the triangle principle, where the distance between the object and each of the known points is known, and the desired point is located at the intersection of the triangles.

The basic principle of trilateration is that to determine the location of an object, you need to know the coordinates of three or more transmitters or base stations that send signals. The object receives these signals and measures the time it takes for the signal to travel from each transmitter to itself. Knowing the speed of signal propagation (e.g., the speed of light), the distance between the object and each transmitter can be calculated.

Then, using the measured distances, you can draw circles or spheres around each transmitter, where the center of the circle or sphere corresponds to the location of the transmitter and the radius corresponds to the distance between the object and the transmitter. The point that satisfies all the measured distances is the location of the object. This is usually the intersection of a circle or sphere that represents the measured distances.

The trilateration method of navigation is widely used in modern technologies, such as global positioning systems, indoor positioning, transport monitoring systems, security systems, and many others. It allows you to pinpoint the location of an object with high accuracy and reliability, making it an indispensable tool in many industries.

3.2.3 Performance characteristics of radio measurements

The performance characteristics of radio measurements are important parameters that determine the quality and reliability of navigation systems that use radio measurements. The main performance characteristics include:

Accuracy: This is a measure of how closely the measurements match the actual values. High accuracy means that the measurements are close to the actual value. The accuracy of radio measurements determines how accurately the location of an object can be determined.

Resolution: This is the smallest interval or step that can be measured by the system. Higher resolution provides more detailed data about the location of an object.

Transmission distance: This is the maximum distance a radio signal can be transmitted. It is important that the radio signal reaches the object without significant loss of signal strength, especially in large rooms or open areas.

Sensitivity: This is a measure of the system's ability to receive weak signals. High sensitivity allows you to detect and measure weak radio signals, which provides more accurate navigation results.

Interference resistance: Radio signals can be subject to loss and distortion from various obstacles such as walls, buildings, or natural objects. It is important that the radio measurement system is immune to such interference and provides stable measurements.

Measurement speed: This is the time it takes for the system to perform one measurement. High measurement speed allows you to get real-time information about the location of the object.

Scalability: This is the ability of the system to handle many simultaneous objects or large amounts of data. The system should be able to efficiently process real-time information for many objects or large spaces.

Considering these performance characteristics, the effectiveness and suitability of radio measurements for specific navigation tasks and applications can be evaluated.

3.3 Radio navigation systems

Radio-based navigation systems are an important component of modern navigation systems and use radio signals to determine the location, path, speed and orientation of objects. They provide precise positioning and navigation in various areas, including air, sea and land transport, as well as indoor environments.

The most famous radio navigation systems are:

1. GPS (Global Positioning System): GPS is a global navigation system that uses satellites to transmit signals that allow you to determine your location anywhere on Earth. GPS is widely used in air, sea and land navigation, as well as in military applications.

2. GLONASS (Global Navigation Satellite System): GLONASS is a Russian global navigation system similar to GPS. It also uses satellites to transmit signals and allows for location and navigation.

3. Galileo: Galileo is a European global navigation system developed by the European Union. It offers similar capabilities to GPS and GLONASS and ensures Europe's independence in the field of navigation.

4. Other radio navigation systems: In addition to global systems, there are also local radio navigation systems that are used for navigation inside buildings, in tunnels, or in

confined areas. These systems use radio signals, infrared or ultrasonic positioning to determine the location.

Radio-based navigation systems play an important role in ensuring the safety, accuracy and efficiency of traffic, navigation in military operations, as well as in everyday life. They provide fast and reliable information about the location of objects, which helps to avoid accidents, improves traffic efficiency and provides convenience to users.

3.3.1 Global Positioning System

The Global Positioning System is a worldwide satellite navigation system that provides location and time information anywhere on Earth. It consists of a network of satellites, ground control stations and GPS receivers. GPS is widely used for navigation, mapping, geodesy and various other applications.

The main components of a GPS system include:

Satellites: The GPS satellite constellation consists of a group of satellites that continuously orbit the Earth. These satellites emit signals containing accurate time and position information.

Earth control stations: These stations are responsible for monitoring and controlling the GPS satellites. They ensure the accuracy of the satellites' clocks and orbits, and they upload updated navigation data to the satellites.

GPS receivers: GPS receivers are devices used by users to receive and process signals from GPS satellites. These receivers calculate the user's position, speed, and time based on signals received from multiple satellites.

The principle of GPS operation is based on trilateration. GPS receivers receive signals from multiple satellites and use the time delay between signal transmission and reception to calculate the distance to each satellite. By combining the distances to several satellites, the receiver can determine its position in three-dimensional space.

GPS provides very accurate position information, usually to within a few meters. It has revolutionized navigation and has become an indispensable tool in various industries such as aviation, maritime navigation, geodesy, transportation, outdoor activities, and emergency services.

In addition to civilian applications, GPS also has military uses, including target tracking, missile guidance, and synchronization of military operations.

In general, GPS has greatly improved our ability to navigate and determine our position with precision, allowing us to navigate in unknown places, plan efficient routes, and accurately determine our position on the Earth's surface[8].

3.3.2 Galileo (European navigation satellite system)

Galileo is a European navigation satellite system developed by the European Satellite Agency (ESA) and the European Commission in cooperation with European countries. The system is designed to provide precise location and navigation services on a global scale.

The main components of the Galileo system include:

Satellites: Galileo consists of a network of satellites located in low Earth orbit. Unlike other navigation systems, such as GPS, Galileo has a larger number of satellites, which provides greater accuracy and reliability of signals.

Control centers: Galileo uses a network of control centers that are responsible for managing and coordinating the operation of the satellites. These centers control the orbits of the satellites, synchronize the clocks, and ensure the accuracy of the navigation data.

Receivers: Users use special Galileo receivers to receive signals from the satellites and determine their position. These receivers provide high accuracy and reliability of position data.

The Galileo system is used in a wide range of industries, including aviation, maritime navigation, transportation, geodesy, rescue operations and everyday use. It allows users to pinpoint their location, plan routes, perform navigation calculations and receive navigation warnings.

The main advantages of the Galileo system include greater accuracy, reliability and independence from other positioning systems. It also provides a greater number of visible satellites, which improves the ability to receive signals in conditions of limited visibility, such as in densely populated urban areas or inside buildings.

All in all, Galileo is a modern and powerful navigation system that complements existing positioning systems, facilitates the development of new technologies, and will benefit a variety of industries that require accurate navigation and location.

3.4 Radio technical means of navigation

Radio navigation aids are used to determine location, orientation and navigation in a variety of fields, including aviation, maritime navigation, road transport, telecommunications, as well as in scientific research and military applications. Radio navigation aids are used to transmit, receive and process radio signals in order to determine the exact location or orientation in space.

The main radio navigation aids include:

Global Positioning System: GPS uses a satellite network to transmit signals that allow receivers to determine their location with high accuracy.

Global Inertial Navigation System: GINS combines data from inertial sensors such as accelerometers and gyroscopes with radio signals to determine location.

Indoor navigation: This is a technology used to navigate inside buildings and structures where GPS signals do not reach. It is based on the use of Wi-Fi, Bluetooth, or other radio signals to determine the location.

Radar systems: Radars use radio signals to determine the position of objects in space. They are widely used in aviation, maritime navigation, and defense.

Radar systems: Radar is used to determine the location and movement of objects using reflected radio signals.

Radio remote control systems: These systems are used to control remotely located objects such as drones, satellites, and automated systems.

Radio-based navigation aids provide precise location, simplify navigation, and ensure safety in various fields. They have become an integral part of the modern world and are widely used in many areas of life.

3.4.1 Radars and radar systems

Radars and radar are important radio engineering tools used to determine the position of objects in space and track their movement. Radar (short for "radio detection and ranging") is a system that uses radio waves to measure distances, directions, and speeds of objects. Radar is based on the principle of sending radio signals and recording the reflected signals after they are reflected from an object.

The main components of a radar system include:

Sender: Generates radio signals and emits them into space.

Antenna: Responsible for emitting radio signals and receiving reflected signals. It can be mobile or static, depending on the application.

Receiver: Receives the reflected signals coming back from objects and analyzes them to determine the distances, direction, and velocity of objects.

Signal processor: Processes the received signals and performs calculations to determine the position and movement of objects.

Radar-based radar is used in many areas, including aviation, maritime navigation, military, meteorology, and scientific research. It provides accurate information about the position and movement of objects, allowing you to control the flight path of aircraft, determine the position of ships at sea, detect hostile objects, and much more.

The use of radar and radar technology can improve safety, efficiency, and accuracy in various situations. They provide navigation and control over objects in difficult conditions, such as poor visibility, long distances, and high speeds. Therefore, radars and radar are an integral part of many navigation, surveillance and security systems.

3.4.2 Radio measurements

Radio measurement is the process of measuring the parameters of radio signals, such as frequency, amplitude, phase, time delay, etc. These measurements are made using special devices that receive radio signals and analyze them to determine the desired parameters.

Radio measurement has a wide range of applications in various industries, including radio engineering, telecommunications, radio navigation, meteorology, and many others. Some examples of radio measurement applications are:

Radio navigation: Systems such as GPS, Glonass, Galileo use radio measurements for location and navigation. Satellites send out radio signals that are received by receivers on the ground, and based on the parameters of these signals, the user's position is determined.

Telecommunications: In radio communications systems, radio measurements are made to determine signal quality, noise, signal strength, etc. This allows to ensure high-quality communication between the sender and the receiver.

Meteorology: Radio measurements are used to collect data on atmospheric conditions, measuring temperature, humidity, atmospheric pressure, wind speed, and other parameters. This data is used for weather forecasting and climate monitoring.

Radio measurements in engineering research: In scientific research, radio measurement is used to measure various parameters such as electromagnetic fields, material properties, data transmission, etc. This provides objective data for analysis and research.

Military applications: In radar and radio reconnaissance and control applications, radio measurement is used to detect, identify and track targets, determine their position and speed.

Radio measurement is an important technology that provides accurate data on radio signals and their parameters. It ensures the efficient functioning of many systems and applications that use radio signals for transmission, navigation, surveillance, and communication.

3.4.3 Radio tracking

Radio Tracking is a method of determining the location of an object by using radio signals. This technology is used to determine the location of moving objects such as animals, vehicles, airplanes, and other objects.

The basic idea of radio tracking is that the object to be tracked has a radio transmitter on it that emits radio signals. These signals are received by special receivers located in different places. The receivers analyze the radio signals and use them to determine the position of the object.

Various methods and technologies are used for radio tracking, including:

The two-radio method: Based on measuring the arrival times of radio signals from two or more radio stations. These measurements can be used to determine the distance between the object and the radio stations, and then determine the position of the object using a trilateration or multilateration algorithm.

GPS systems: The Global Positioning System is one of the most commonly used radio tracking methods. GPS uses a network of satellites that emit radio signals and receivers on the ground that receive these signals and determine the position using a trilateration algorithm.

Radio measurements: Used to measure the parameters of radio signals emitted by an object. These measurements allow you to determine the distance to the object and its direction, which helps determine its position.

Radars: Radars are radar systems used to detect, locate, and track objects using reflected radio signals. Radars are used in aviation, maritime, defense, and other fields for navigation and security.

Radio tracking is an important technology that finds application in many industries, including scientific research, military operations, geodesy, transportation systems, and more. It allows you to determine the location of objects with high accuracy and provides important data for decision-making and control[9].

3.4.4 Radio compasses and gyroscopes

Radiocompasses and gyroscopes are important radio navigation aids used to determine the orientation and direction of objects.

Radio compasses: A radio compass is a device that uses radio signals to determine direction. It works on the principle of determining the azimuth (angular direction) to the radio signals coming from radio stations. Radio compasses are used in aviation, navigation, and other industries where accurate direction determination is essential.

Gyroscopes: A gyroscope is a device that measures or maintains the constancy of an object's orientation in space. They are based on the principle of conservation of angular momentum of a body. Gyroscopes are used to determine and maintain the orientation of vehicles, airplanes, spacecraft, and other objects. They help control the movement of an object and ensure stability.

When used together, radio compasses and gyroscopes can be used to determine an object's direction of travel and orientation. Radio compasses provide absolute azimuth measurements, while gyroscopes provide orientation change measurements and object motion detection. The combination of these two technologies provides complete information about the position and direction of an object in space.

Radio compasses and gyroscopes are used in various industries, including aviation, maritime, automotive, military operations, scientific research, and others. They are important components of navigation and control systems, helping to ensure the accurate determination of the position and orientation of objects in space.

3.5 Influence of factors on the quality of radio navigation

The accuracy and reliability of radio navigation can be affected by various factors that can distort signals and reduce the quality of the system. In this essay, we will consider the impact of the main factors on the quality of radio navigation and ways to improve these parameters.

Interference and signal attenuation:

- Influence of physical objects: Buildings, mountains, trees, and other obstacles can block radio signals and cause signal attenuation. This can result in signal distortion, signal loss, or reduced signal-to-noise ratio. To overcome this effect, antenna systems with better signal permeability and fading compensation algorithms can be used.

- Signal scattering: Multiple scattering occurs when a radio signal is scattered from different surfaces and reaches the receiver from different directions. This can lead to multipath effects, multiple copies of the signal, and changes in signal amplitude and phase. To avoid this effect, filtering and detection algorithms can be used to separate the main signal from multipath components.

Interference:

- Electromagnetic interference: The presence of other radio devices, electromagnetic fields, and noise sources can cause electromagnetic interference, which reduces radio signal quality and navigation accuracy. To avoid this effect, you can use antenna systems with better electromagnetic compatibility, apply filtering algorithms, and use spectral analytics to isolate the desired signal.

- Intersystem interference: When different radio systems are used simultaneously, interference can occur when signals from one system affect the operation of another system. This can lead to signal distortion and reduced navigation accuracy. To avoid this impact, it is necessary to carefully plan the spectral placement and use spectrum management algorithms.

Geometry and accuracy errors:

- Geometric errors: Satellite geometry can affect location accuracy. Improper satellite configuration can lead to increased geometric errors and reduced accuracy. This can be avoided by optimizing satellite placement and using geometric error correction algorithms.

- Signal accuracy: The accuracy of the radio signal itself, its phase and amplitude can affect the accuracy of radio navigation. Signal instability, noise, and other parameters can cause errors in positioning. Signal correction algorithms and device calibration can be used to improve accuracy.

The influence of factors on the quality of radio navigation is an important aspect of the development and operation of navigation systems. Understanding these factors and their impact on signals helps to improve the technologies and algorithms used in radio navigation. To achieve high quality navigation, it is necessary to take into account interference, interference and other factors, and to apply advanced technologies and error compensation algorithms. This will ensure accurate and reliable location and navigation in various areas and conditions.

3.5.1 Signal attenuation and interference

In radio systems, signal fading and interference are among the main factors that affect the quality of signal transmission and reception. They can significantly degrade the quality of communication and navigation, cause signal distortion, and increase the likelihood of errors. In this essay, we will consider the main causes of signal attenuation and interference, as well as methods of dealing with these phenomena.

Signal attenuation occurs when radio waves are transmitted in the environment and has the following types:

Spatial fading: This is the attenuation due to the propagation of the signal in space. Depending on the frequency of the signal and the characteristics of the medium (e.g., air, water, buildings), the signal can experience various types of loss. Spatial fading can be linear or nonlinear, and can be compensated for by amplifying the signal or using relaying.

Radiation: Radiation occurs as a result of signal scattering at an obstacle. This can be scattering on any object that is in the path of the signal, such as a wall, tree, or any other object. This results in a loss of signal energy and a change in its characteristics.

Fresnel attenuation: Fresnel fading occurs when a signal propagates through narrow openings, such as between buildings or other obstacles. This results in wave interference and reduced signal quality. Reducing Fresnel fading can be achieved by changing the direction of the antenna or using antennas with a higher directivity.

Interference in radio systems can be physical objects, electromagnetic frequency bands, noise, and other signals that distort signal transmission and reception. The main types of interference include:

Interference from other sources: This can be signals from other devices or systems operating in the same frequency band. This can cause interference and signal distortion. Engineering solutions such as using filters and signal encoding can help manage this interference.

Interference in the indoor environment: Buildings, walls, furniture, and other objects in the indoor environment can interfere with radio signals. This can result in reduced signal strength and distortion. Using antennas with greater directionality, relaying the signal, and placing antennas in open spaces can help reduce the impact of these interferences.

Signal fading and interference are an integral part of radio navigation and data communications. Understanding these factors and their impact on signal quality allows for the development and application of appropriate technologies and techniques that improve navigation quality and ensure reliable data transmission. Further research and development of technologies in this area will help reduce the impact of signal fading and interference on radio navigation.

3.5.2 Measurement accuracy and reliability

Measurement accuracy and reliability are important characteristics of radio navigation systems. These indicators are determined by the level of errors that can affect the measurement results.

Measurement accuracy indicates the degree to which the measurement results correspond to the actual values. The smaller the measurement error, the more accurate the result is considered. To achieve high measurement accuracy in radio navigation systems, various methods are used, such as the use of more accurate signals, error correction algorithms, and the use of multiple satellites or stations.

Measurement reliability indicates the stability and uninterrupted operation of radio navigation systems. This means that the system must continue to operate reliably even in the event of errors, noise, or other internal or external influences. To ensure the reliability of measurements in radio navigation systems, various techniques are used, such as error correction, signal integrity checking algorithms, backup mechanisms and disaster recovery systems.

To achieve high accuracy and reliability of measurements in radio navigation systems, it is important to systematically analyze and correct errors, use standardized protocols, develop high-quality equipment, and constantly improve data processing algorithms. This is the only way to ensure high accuracy and reliability of measurements in radio navigation systems.

3.6 Current trends and prospects for the development of radio navigation

Modern radio navigation is constantly evolving and includes a wide range of technologies and systems. The main trends and prospects for the development of radio navigation include the following aspects:

Improvement of positioning systems. GPS and GLONASS systems continue to improve in order to provide higher accuracy and reliability of measurements. The introduction of new satellite systems, such as Galileo and BeiDou, is expanding global positioning capabilities.

Use of Low Earth Orbit satellites. Companies such as SpaceX and OneWeb are developing networks of LEO satellites to improve the availability and accuracy of navigation services. This could allow for lower latency signals and indoor navigation.

Development of indoor navigation systems. Technologies such as Wi-Fi positioning and Bluetooth Low Energy are becoming increasingly common in indoor navigation systems. They allow users to locate themselves inside buildings and help expand navigation capabilities in enclosed spaces.

Use of additional signal sources. Developments in technology, such as multi-sensor systems and combined navigation solutions, allow for the combination of information from different sources, such as satellite systems, Inertial Navigation Systems sensors, cameras, etc., to provide more accurate and reliable positioning.

Expanding applications. Radio navigation finds its application in various fields, such as automotive, aviation, navigation, geodesy, rescue operations, and others. The development prospects lie in the use of radio navigation in new areas, such as drones, smart cities, real-time location, and the Internet of Things.

In short, radio navigation is a key technology for determining location and orientation in the modern world. Its development is aimed at ensuring higher accuracy, availability and reliability of measurements, as well as expanding applications in various industries. This opens up new opportunities to improve our perception of the world and develop innovative solutions.

3.6.1 Improving satellite navigation systems

Improvement of satellite navigation systems is one of the most important trends in modern radio navigation. Over the past decades, significant steps have been taken to improve satellite systems, in particular GPS, GLONASS (Global Navigation Satellite System) and Galileo (European Navigation Satellite System). The main areas of improvement include the following aspects: improving accuracy, increased reliability, expanding functionality, integration with other systems, expanding geographic coverage.

Improving accuracy. One of the main objectives of improving satellite systems is to improve positioning accuracy. This is achieved by increasing the number of satellites used for positioning, improving signal processing algorithms, and using additional sources of information such as Inertial Navigation Sensors or correction signals.

Increased reliability. Improvements to satellite systems are also aimed at increasing the reliability of measurements and ensuring signal stability in various conditions. This includes developing error correction algorithms, managing satellite constellations, and improving antenna support systems.

Reducing delays. Signal delays can affect positioning accuracy, especially in high speed environments or when using real-time navigation. Therefore, improvements in satellite systems are aimed at reducing signal delays and improving the speed of position data acquisition.

Expanding functionality: Modern satellite navigation systems are improving not only in terms of accuracy and reliability, but also in terms of functionality. This includes support for additional services, such as measuring height, speed, inclination, time synchronization, positioning in tall buildings or indoors.

Integration with other systems: Modern trends involve the integration of satellite navigation systems with other technologies, such as Wi-Fi, Bluetooth, INS sensors, and others. This allows you to get more accurate and reliable location data, especially indoors or in conditions where the satellite signal is not available.

Expanding geographic coverage: One of the development prospects is to expand the geographical coverage of satellite navigation systems. New satellites are planned to be launched, which will provide navigation signal coverage in all parts of the world, including remote regions and offshore areas.

All these trends and prospects are aimed at improving the quality of satellite navigation to provide more accurate, reliable and versatile positioning for various industries, including the automotive industry, aviation, shipping, geodesy and other areas of activity.

3.6.2 Use of new technologies and algorithms

The use of new technologies and algorithms is an important aspect of the development of radio navigation. Modern advances in electronics, computer technology and computing power make it possible to implement new approaches to positioning and navigation. Some of the most significant new technologies and algorithms include: Integrating satellite navigation with other sensors, expanding the spectrum of satellite signals, developing new signal processing algorithms, using artificial intelligence, developing 5G networks and the Internet of Things.

Integration of satellite navigation with other sensors. Using satellite navigation in conjunction with other sensors such as accelerometers, gyroscopes, magnetometers, and barometers allows for more accurate and reliable location and orientation data. Integration of inertial navigation sensors with satellite systems allows you to correct errors associated with signal loss or inadequate satellite coverage in indoor environments or places with a large number of obstacles.

Expanding the range of satellite signals: New methods of modulating and encoding satellite signals are being developed to improve navigation accuracy and reliability. For example, the use of multi-beam signals transmitted from different directions or from different satellites allows for better error correction and improved positioning accuracy.

Development of new signal processing algorithms: The invention of new signal processing algorithms is a key element in improving radio navigation. For example, filtering, adaptive smoothing, and statistical processing algorithms can reduce the impact of noise and distortion on signals, which improves measurement accuracy. Algorithms are also being developed to detect and compensate for errors associated with signal propagation in different environments, such as multipath, fading, and reflection.

Use of artificial intelligence: AI is increasingly being used in radio navigation. Machine learning and deep learning algorithms are used to improve positioning, motion prediction, and error detection and correction. AI allows navigation systems to learn from experience, adapt to changing conditions, and provide more accurate and reliable navigation.

Development of 5G networks and the Internet of Things (IoT). 5G and IoT networks provide new opportunities to improve radio navigation. They provide fast and stable data exchange between devices and systems, which allows for up-to-date information for accurate positioning. IoT allows you to connect a variety of sensors and devices, which expands the capabilities of radio navigation and provides more accurate location determination.

The use of new technologies and algorithms in radio navigation helps to improve the accuracy, reliability and speed of positioning. These development prospects open up new opportunities in the field of autonomous vehicles, drones, virtual reality, smart cities and other areas where accurate positioning is an important factor.

3.6.3 Integration of radio navigation with other systems

Integration of radio navigation with other systems is a key aspect of the development and improvement of navigation solutions. It allows combining the advantages of different technologies and systems to obtain more accurate, reliable and comprehensive positioning. Some of the main areas of integration of radio navigation with other systems are.

Integration with satellite systems. Radio navigation can be integrated with global satellite systems such as GPS, Glonass, Galileo, and others. This allows for more precise positioning by combining information from different satellite systems and using filtering and data processing methods.

Integration with inertial systems. Inertial systems, such as gyroscopes and accelerometers, can be integrated with radio navigation to improve positioning accuracy and stability. This combination compensates for errors due to displacement and vibration and ensures continuous position measurement even in conditions of signal loss.

Integration with network systems. Radio navigation can be integrated with networked systems such as mobile networks, Wi-Fi, and Bluetooth. This allows you to use information about signals and access points for indoor positioning and provide navigation services based on local networks.

Integration with additional sensors. Radio navigation can be combined with other sensors such as video cameras, laser scanners, thermal sensors, etc. This allows you to get additional information about the environment and objects to improve the accuracy and reliability of navigation.

Integration with artificial intelligence systems. The use of artificial intelligence techniques such as machine learning and deep learning can improve the quality of radio navigation. Artificial intelligence allows you to analyze large amounts of data, predict errors, and optimize algorithms to obtain more accurate and efficient positioning.

Integration of radio navigation with other systems opens up broad prospects for developing new applications and improving the quality of navigation solutions. This allows for more accurate, reliable and comprehensive positioning results, which is of great importance for such areas as autonomous navigation, transportation, telecommunications, rescue operations and many others.

3.7 Conclusions to the chapter

As a result, the study of the theory of radio navigation proved to be very interesting and important for understanding the principles and application of radio positioning and navigation methods. The research has confirmed that radio navigation has wide application possibilities in various industries, including aviation, shipping, automotive industry, and others.

The study of the basic principles of radio navigation made it possible to emphasize the importance of modern satellite systems, such as GPS and Galileo, as reliable and accurate sources of location information. In addition, it turned out that the integration of radio navigation with other systems, the use of new technologies and algorithms, such as Indoor navigation, have an impact on improving the accuracy and reliability of navigation measurements.

However, it has been found that there are factors such as signal fading and interference that can affect the quality of radio navigation. However, with the advent of new technologies and improved algorithms, it is possible to reduce these negative effects and increase the efficiency of navigation systems.

Thus, the study of radio navigation theory confirms its importance and development prospects. Understanding the principles and application of radio engineering methods allows creating more accurate, reliable and efficient navigation systems, which is important for various industries and contributes to further technological progress in this area[10].

CHAPTER 4 DETERMINE THE POSITION AND ROUTE OF THE USER IN THE BUILDING

4.1 Determining the user's position

Identification technologies are very common in the modern world. Almost everyone has a mobile device with multiple sensors. Wi-Fi sensors are most often used to detect a device indoors. Wi-Fi sensors can solve two main tasks: measuring the signal and directly determining the location. Signal measurement can be performed in different ways to solve the first task. The received signal strength (RSS), the angle method (AOA), and time-based methods are the main ones.

To simplify the process of determining the user's position, instead of using a geographic coordinate system, we set up our own coordinate grid in the room with a 1-meter step. For this purpose, we place the origin of the coordinate system in one of the corners of the room. This way, you can easily measure the distance from this coordinate system to the routers.

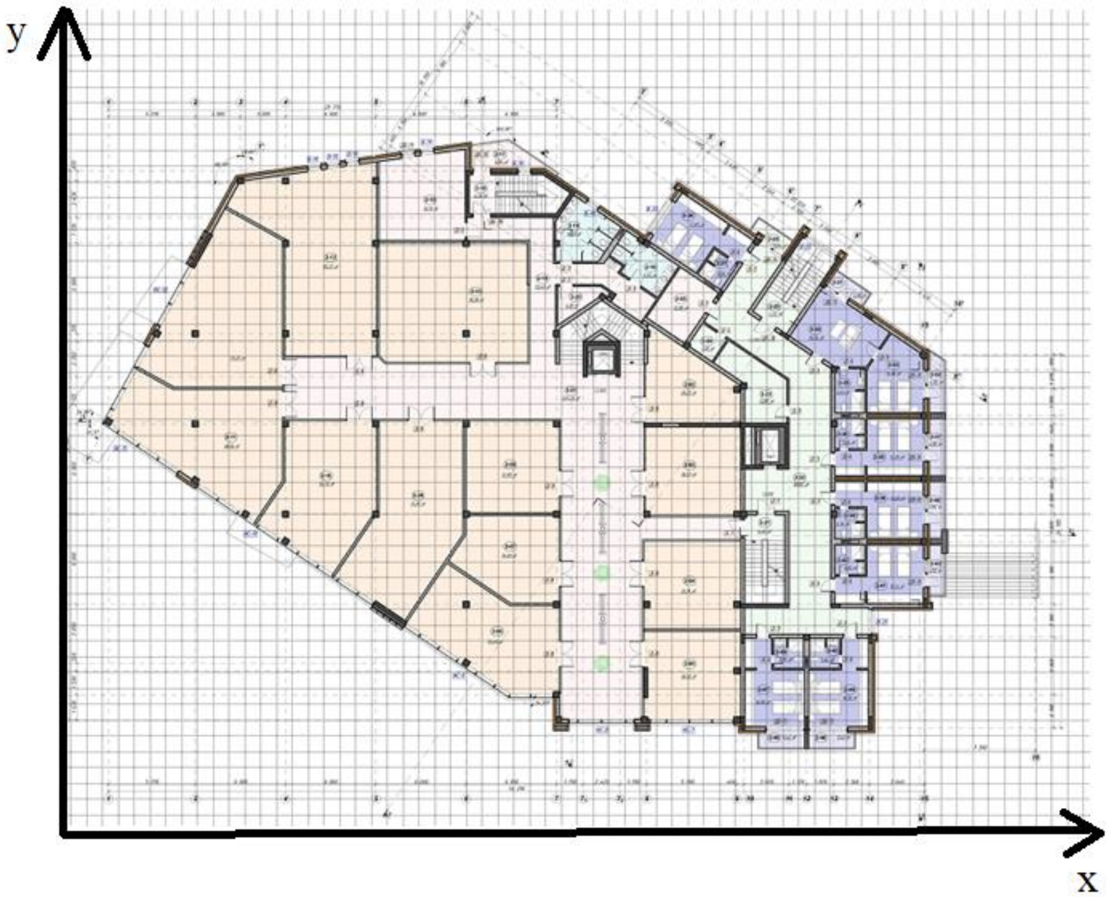

Fig. 4.1 Building layout with coordinate grid

The RSS method is described - a method that is available only for radio signals. It allows you to measure the distance from an unknown node to another. The RSS data can be used for two types of location determination, the fingerprint method, which requires a training stage to create a fingerprint map, or the trilateration method. The signal propagation model establishes a relationship between the strength of the received signal and the distance. To determine the distance to an access point, the article provides the following formula:

$$PL(d) = P_t - \mathrm{P(d)} = \mathrm{PL}(d_0) + \mathrm{n10lg}\frac{d}{d_0} \quad (1)$$

where d is the distance to the device, PL(d) is the signal power loss at a distance d, Pt is the transmitter power, P(d) is the signal power at the receiver device at a distance d, d0 - distance of 1 meter, n - signal propagation coefficient in the environment.

Next, the data obtained for each access point is used in the trilateration method.

The trilateration method allows you to position the mobile device in the room. This is achieved by determining the relative location of the device using a geometric distance calculation.

The calculation requires three access points for which their coordinates are known. Then we can build the equation of circles:

$$d_1^2 = (x_1 - x)^2 + (y_1 - y)^2 \quad (2)$$

$$d_2^2 = (x_2 - x)^2 + (y_2 - y)^2 \quad (3)$$

$$d_n^2 = (x_n - x)^2 + (y_n - y)^2 \quad (4)$$

where $x1$, $x2$, xn, $y1$, $y2$, yn are the coordinates of the access points.

$d1$, $d2$, dn are the distances from the access points to the receiver device

So, the point of intersection of these three circles is the relative location of the receiver device. Schematically, this can be shown as follows:

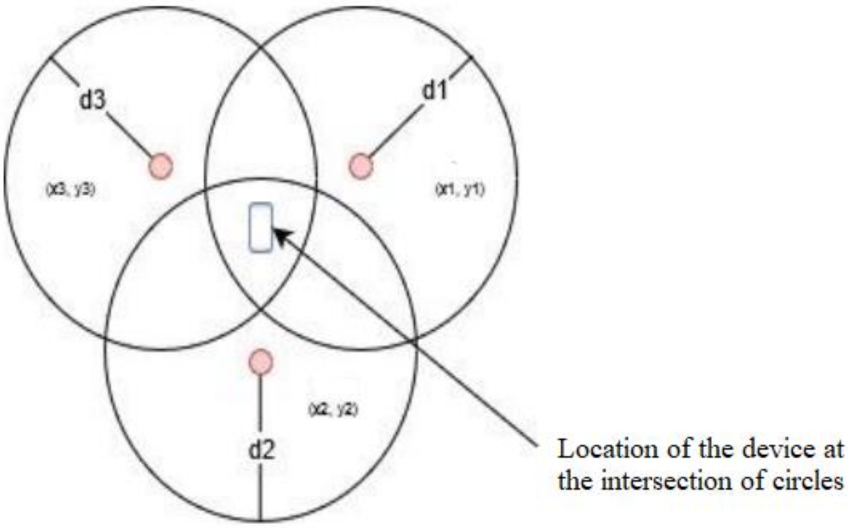

Fig. 4.2 Schematic representation of the trilateration method

To implement this algorithm for determining the user's position, a program was written, the code of which is shown in Appendix A.

4.2 Indoor route planning

The next step after determining the user's location is to build a route. The route is laid from the location to the destination, which the user has to choose independently, this can be done using a simple command line interface or a graphical interface.

After selecting the end point, the program must implement a path search algorithm to calculate the shortest path from the user's current location to the destination. The most commonly used algorithm for this is the A* algorithm, which is efficient and effective for most navigation tasks.

The A* algorithm is one of the most popular algorithms for finding a path in graphs. It is used to find the shortest path from the source node to the target node, taking into account the weights of the edges and heuristic evaluation. The A* algorithm combines the effectiveness of the breadth-first search (BFS) algorithm and the greedy algorithm.

The A* algorithm works by gradually expanding the graph by considering neighboring nodes. The algorithm selects the next node to be considered from an open list containing nodes that have not yet been fully explored. For each considered node, the algorithm calculates a total cost, which consists of the weight of the path from the starting node to the current node and a heuristic estimate from the current node to the target node. This heuristic estimate is usually an estimate of the shortest possible path between two nodes based on some criterion, such as Euclidean distance or Manhattan distance.

The algorithm continues to consider neighboring nodes until the target node is reached or until the open list is empty. If the target node has been reached, the algorithm terminates and the shortest path found is returned. If the open list becomes empty and the target node has not been reached, it means that there is no available path to the target node and the algorithm terminates without a result.

The A* algorithm has several advantages that make it effective in different areas. It is able to find the shortest path with the minimum weight, which makes it useful in optimal path planning problems. In addition, the algorithm can be optimized with certain techniques, such as the use of priority queues or hash tables, to speed up computation. This makes it suitable for large graphs and real-time systems.

The A* algorithm is widely used in various fields such as robotics, computer games, autonomous cars, navigation, and many others where it is important to find the optimal path in large graphs with weights. Using the A* algorithm allows you to achieve efficiency and accuracy in pathfinding, which is a key factor in many applications and systems.

When building a route, it is necessary to take into account restrictions in the form of building structures and objects that the user will not be able to pass through. Figure 4.3 shows such restrictions in red. An example of a built route is shown in Figure 4.4.

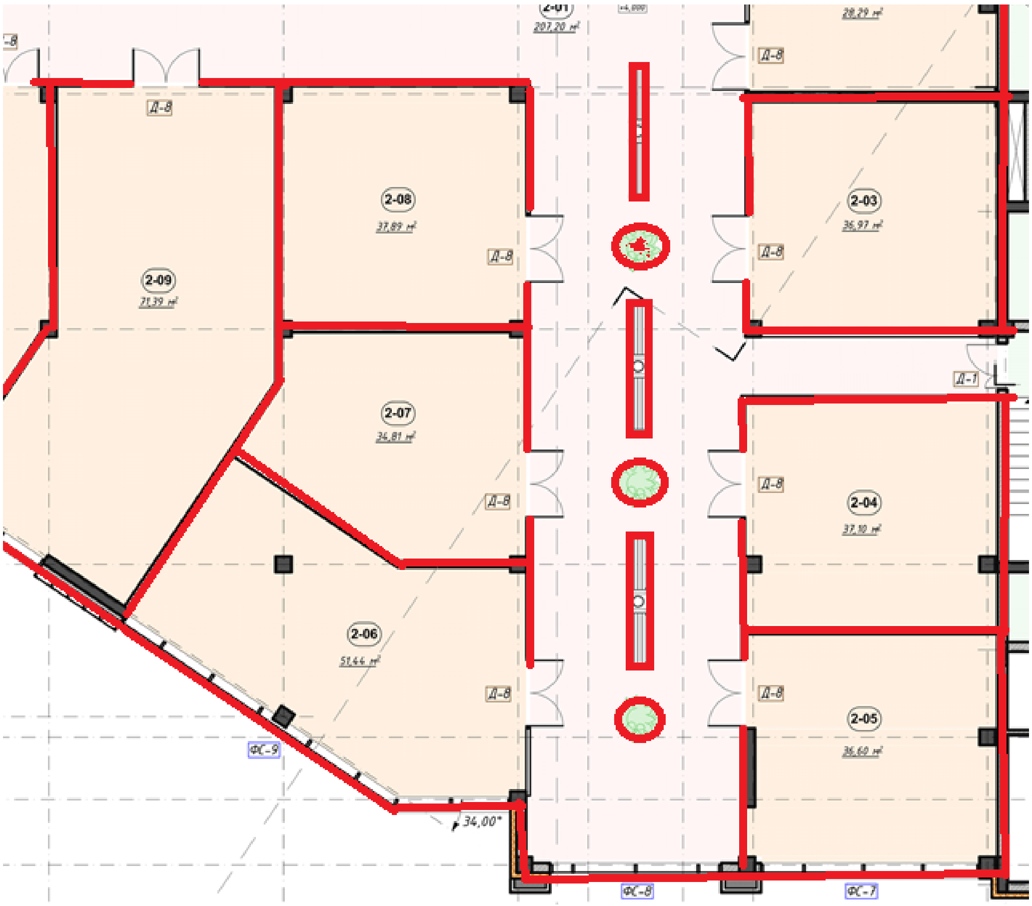

Fig. 4.3 Example of route restrictions

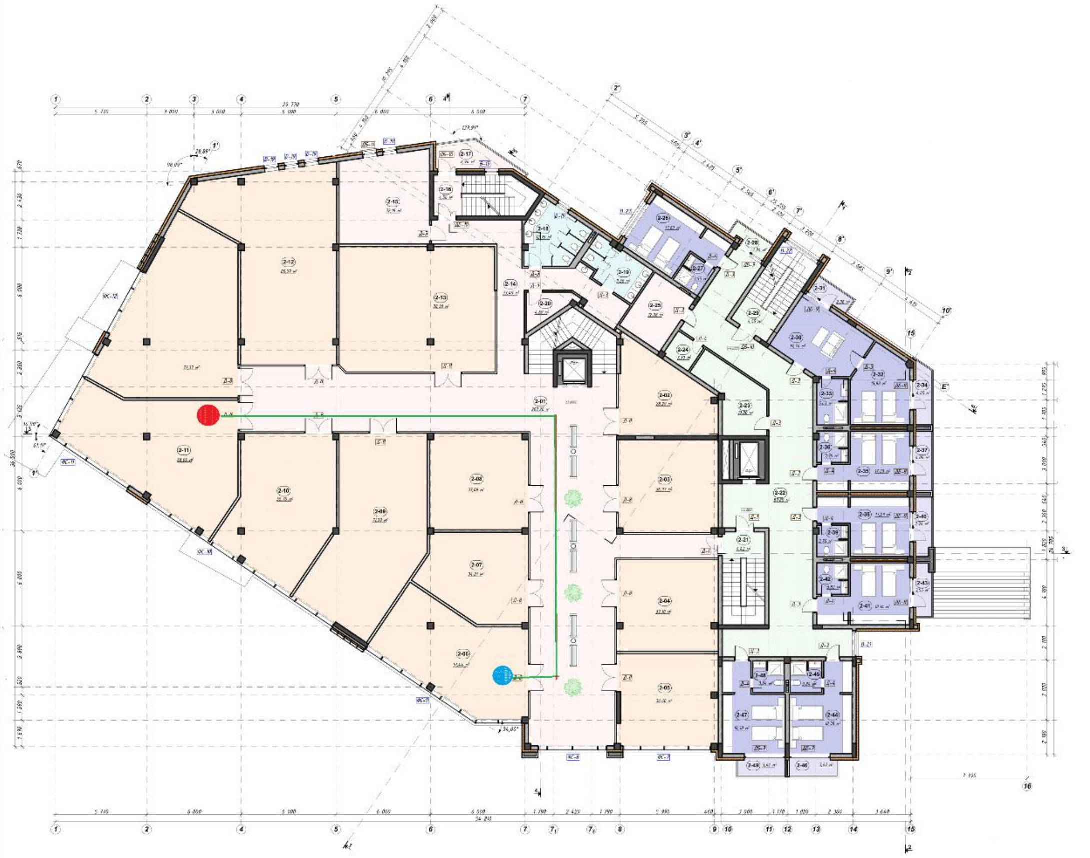

Fig. 4.4 An example of the route laid

The program code shown in Appendix B has been developed, which implements the construction of the route using the algorithm considered.

CONCLUSIONS

In this bachelor's thesis, a detailed analytical work was carried out on the problem of an individual mobile indoor navigation system. Various technologies and methods used for indoor navigation, such as wi-fi, bluetooth, radio measurement, trilateration, and others, were studied.

The results of the study showed that a customized mobile indoor navigation system is an important technology with many benefits for users. It allows people to efficiently navigate inside buildings, find the best way to the right places, and get additional information about the environment.

One of the key advantages of a customized mobile navigation system is its ease of use. Users can get the necessary information about their location and routing on their smartphones or other mobile devices. This provides them with flexibility and convenience in using the indoor navigation system.

It has also been found that the accuracy of the navigation system is critical to meeting the needs of users. Research on different technologies has shown that a combination of several methods, such as wi-fi, bluetooth, and satellite navigation (gps, galileo), can improve the accuracy and reliability of indoor location.

In addition, an individualized mobile navigation system opens up new opportunities for the development of various industries, such as trade, transportation, tourism, and many others. It allows you to create personalized experiences for users by providing them with information about the nearest objects, offers and services inside buildings.

An individual mobile navigation system has been developed that uses Wi-Fi to determine the user's position inside large rooms such as airport terminals, shopping centers, train stations, etc. The advantage of the proposed system is the absence of the need to install additional equipment, since Wi-Fi routers and access points are already installed in the above-mentioned premises and the role of the user equipment is performed by the smartphone hardware, on which it is only necessary to install the appropriate software.

In this work, we have developed software that allows determining the user's position based on Wi-Fi signals by trilaterating the route to a given point, visualizing the route and visualizing the user's current location on the route.

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APPENDIX A

```
IMPORT MATH

DEF CALCULATE_DISTANCE(RSSI, TX_POWER, N):
    """
    IS A FUNCTION FOR CALCULATING THE DISTANCE BASED ON THE RSSI SIGNAL AND THE PARAMETERS OF THE TRILATERATION MODEL.
    :PARAM RSSI: IS THE VALUE OF THE RSSI SIGNAL.
    :PARAM TX_POWER: IS THE REPORTED VALUE OF THE TRANSMITTER POWER.
    :PARAM N: IS AN EXPONENTIAL VARIABLE RESPONSIBLE FOR SIGNAL DECAY.
    :RETURN: DISTANCE IN METERS.
    """
    RETURN 10 ** ((TX_POWER - RSSI) / (10 * N))

DEF TRILATERATION(LOCATIONS, DISTANCES):
    """
    A FUNCTION FOR DETERMINING USER COORDINATES USING THE TRILATERATION METHOD.
    :PARAM LOCATIONS: A LIST WITH THE COORDINATES OF WI-FI ACCESS POINTS IN (X, Y) FORMAT.
    :PARAM DISTANCES: A LIST WITH DISTANCES FROM THE USER TO EACH WI-FI ACCESS POINT.
    :RETURN: USER COORDINATES IN (X, Y) FORMAT.
    """
    IF LEN(LOCATIONS) < 3 OR LEN(LOCATIONS) != LEN(DISTANCES):
        RETURN NONE
```

```
    X1, Y1 = LOCATIONS[0]
    X2, Y2 = LOCATIONS[1]
    X3, Y3 = LOCATIONS[2]

    D1 = DISTANCES[0]
    D2 = DISTANCES[1]
    D3 = DISTANCES[2]

    A = 2 * X2 - 2 * X1
    B = 2 * Y2 - 2 * Y1
    C = D1 ** 2 - D2 ** 2 - X1 ** 2 + X2 ** 2 - Y1 ** 2 + Y2 ** 2
    D = 2 * X3 - 2 * X2
    E = 2 * Y3 - 2 * Y2
    F = D2 ** 2 - D3 ** 2 - X2 ** 2 + X3 ** 2 - Y2 ** 2 + Y3 ** 2

    X = (C * E - F * B) / (E * A - B * D)
    Y = (C * D - A * F) / (B * D - A * E)

    RETURN X, Y

# EXAMPLE OF USE

# COORDINATES OF WI-FI ACCESS POINTS
LOCATIONS = [(0, 0), (10, 0), (0, 10)]

# DISTANCE FROM THE USER TO EACH WI-FI ACCESS POINT (IN METERS)
DISTANCES = [5, 7, 8]

# ПАРАМЕТРИ TRILATERATION MODELS (MAY VARY DEPENDING ON THE ENVIRONMENT)
```

TX_POWER = -65

REPORTED VALUE OF THE TRANSMITTER POWER

N = 2

EXPONENTIAL VARIABLE RESPONSIBLE FOR SIGNAL DECAY

CALCULATING DISTANCES BASED ON RSSI VALUES AND PARAMETERS OF THE TRILATERATION MODEL

DISTANCES = [CALCULATE_DISTANCE(RSSI, TX_POWER, N) FOR RSSI IN RSSI_VALUES]

DETERMINING THE USER'S COORDINATES USING THE TRILATERATION METHOD

USER_LOCATION = TRILATERATION(LOCATIONS, DISTANCES)

IF USER_LOCATION IS NOT NONE:

PRINT(USER_LOCATION)

ELSE:

PRINT

APPENDIX B

```
# INSTALL LIBRARIES

# BIBLIOGRAPHY IS NECESSARY FOR VISUALIZATION
! PY -M PIP INSTALL MATPLOTLIB

#
! PY -M PIP INSTALL NETWORKX

# LIBRARY FOR WORKING WITH MATRICES
! PY -M PIP INSTALL NUMPY

# ALGORITHM FOR WORK, USED FOR CUSTOM IMPLEMENTATION, FOR FINDING SHORTEST PATHS IN GRAPHS
! PY -M PIP INSTALL HEAPQ_MAX

# IMPORT THE NECESSARY LIBRARIES
IMPORT MATPLOTLIB.PYPLOT AS PLT
IMPORT NETWORKX AS NX
IMPORT NUMPY AS NP
IMPORT HEAPQ

# CALCULATE THE DISTANCE BETWEEN TWO POINTS
DEF HEURISTIC(A, B):
    RETURN NP.SQRT((B[0] - A[0]) ** 2 + (B[1] - A[1]) ** 2)



# CREATE AN ALGORITHM
DEF ASTAR(ARRAY, START, GOAL):
```

```
# LIST OF POSSIBLE NEIGHBORS
NEIGHBORS = [(0,1),(0,-1),(1,0),(-1,0),(1,1),(1,-1),(-1,1),(-1,-1)]

CLOSE_SET = SET()
CAME_FROM = {}
GSCORE = {START:0}
FSCORE = {START:HEURISTIC(START, GOAL)}
OHEAP = []

HEAPQ.HEAPPUSH(OHEAP, (FSCORE[START], START))

WHILE OHEAP:
   CURRENT = HEAPQ.HEAPPOP(OHEAP)[1]

   IF CURRENT == GOAL:
      DATA = []
      WHILE CURRENT IN CAME_FROM:
         DATA.APPEND(CURRENT)
         CURRENT = CAME_FROM[CURRENT]
      RETURN DATA

   CLOSE_SET.ADD(CURRENT)
   FOR I, J IN NEIGHBORS:
      NEIGHBOR = CURRENT[0] + I, CURRENT[1] + J
      TENTATIVE_G_SCORE = GSCORE[CURRENT] +
HEURISTIC(CURRENT, NEIGHBOR)

      IF 0 <= NEIGHBOR[0] < ARRAY.SHAPE[0]:
         IF 0 <= NEIGHBOR[1] < ARRAY.SHAPE[1]:
            IF ARRAY[NEIGHBOR[0]][NEIGHBOR[1]] == 2:
```

```
                    CONTINUE
                ELSE:
                    # ARRAY BOUND Y WALLS
                    CONTINUE
            ELSE:
                # ARRAY BOUND X WALLS
                CONTINUE

            IF NEIGHBOR IN CLOSE_SET AND TENTATIVE_G_SCORE >= GSCORE.GET(NEIGHBOR, 0):
                CONTINUE

            IF TENTATIVE_G_SCORE < GSCORE.GET(NEIGHBOR, 0) OR NEIGHBOR NOT IN [I[1]FOR I IN OHEAP]:
                CAME_FROM[NEIGHBOR] = CURRENT
                GSCORE[NEIGHBOR] = TENTATIVE_G_SCORE
                FSCORE[NEIGHBOR] = TENTATIVE_G_SCORE + HEURISTIC(NEIGHBOR, GOAL)
                HEAPQ.HEAPPUSH(OHEAP, (FSCORE[NEIGHBOR], NEIGHBOR))

    RETURN FALSE
DEF INTERPOLATE_PATH(PATH):
    INTERPOLATED_PATH = []
    FOR I IN RANGE(LEN(PATH) - 1):
        START = PATH[I]
        END = PATH[I + 1]
        # ADD THE START NODE TO THE PATH
        INTERPOLATED_PATH.APPEND(START)
        # IF THE MOVE IS DIAGONAL, INTERPOLATE THE CELL IN BETWEEN
        IF ABS(START[0] - END[0]) == 1 AND ABS(START[1] - END[1]) == 1:
```

```
        INTERPOLATED_PATH.APPEND((START[0], END[1]))
    # ADD THE GOAL NODE TO THE PATH
    INTERPOLATED_PATH.APPEND(PATH[-1])
    RETURN INTERPOLATED_PATH
DEF DRAW_PATH(GRID, PATH):
    # CREATE A COPY OF THE GRID
    GRID_COPY = GRID.COPY()

    # MARK THE PATH ON THE GRID COPY
    FOR NODE IN PATH:
        GRID_COPY[NODE[0]][NODE[1]] = 3

    # CREATE A COLOR MAP FOR VISUALIZATION
    COLORS = ['WHITE', 'BLACK', 'RED', 'BLUE']
    CMAP = PLT.CM.COLORS.LISTEDCOLORMAP(COLORS)

    # DRAW THE GRID
    PLT.IMSHOW(GRID_COPY, CMAP=CMAP, VMIN=0,
VMAX=LEN(COLORS) - 1)

    # SHOW THE PLOT
    PLT.SHOW()
# USAGE EXAMPLE:

# ANY MAP CAN BE REPRESENTED AS A MATRIX WITH TWO TYPES OF CORRESPONDING OBSTACLES AND NO OBSTACLES WHERE THERE IS AN OBSTACLE THERE IS AN OBSTACLE THERE 0 WHERE THERE IS NO OBSTACLE THERE 2
NMAP = NP.ARRAY([
    [0, 0, 0, 2, 0],
```

```
    [2, 2, 0, 0, 0],
    [0, 0, 0, 2, 0],
    [0, 2, 2, 2, 2],
    [0, 0, 0, 0, 0]
])
DRAW_PATH(NMAP, [])
START = (0, 0)
END = (4, 2)
PATH = ASTAR(NMAP, START, END)






PRINT("PATH", PATH)




COMPLETE_PATH_LIST = INTERPOLATE_PATH(PATH)   # RENAME THIS VARIABLE
PRINT("COMPLETE PATH", COMPLETE_PATH_LIST)

DRAW_PATH(NMAP, PATH)
```