Construction Automatic Positioning System of a Moving Object Based on the Readings of Bluetooth Beacons and Modified Multelatation Method

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Abstract. The article discusses the solution to the problem of positioning a movable mobile object in a controlled area. The proposed solution is based on the construction of a sensor network from Bluetooth Low Energy radio beacons in the controlled area. The interaction of the mobile device and the sensor network is proposed to be carried out via a Bluetooth communication channel of specification not lower than 5.0 by obtaining the values of the RSSI signal levels of each radio beacon. The room has its own absolute coordinate plane. According to the multilateration method, each triplet of beacons forms its own relative coordinate plane. The developed algorithm also considers the issue of converting relative coordinates to absolute ones. At the end of the study, a description is given of an experimental study on positioning a mobile phone in a 5 by 10-meter room.

1. Introduction
According to the program "Development of the digital economy in Russia until 2035," one of the technologies that determine the transition to the digital economy is identification technology [1], the development of the methods of which the work is aimed at. The implementation of this kind of technology will make it possible to switch to unmanned control of product movement by reducing the requirements for the installation of sensor equipment and additional control and self-control algorithms. This article focuses on the development of new identification technologies for the development of the AutoNet market. In addition, it will allow you to upgrade automated transport systems [1], such as RTLS (from the English real-time Locating Systems — real-time positioning system) and ADAS (from the English Advanced Driver-Assistance Systems - driver assistance system). The development of methods for constructing RTLS and ADAS systems plays an important role in the implementation of projects of "smart industries" and "smart cities", which are one of the most important and priority directions of the development of sociotic systems.

The main problems in the implementation of autonomous navigation systems currently include:
(1). Lack of high-precision information and communication technologies with low energy consumption for the implementation of methods of optimal control of mobile objects (software), including unmanned vehicles.
(2). Lack of efficient and resistant to external influences sensors and sensor networks that provide software positioning and monitoring of their movement with high accuracy.
(3). Poor development of cybersecurity issues of the proposed sensor networks for positioning and monitoring software.
Proceeding from this, it is required to develop new science-intensive technologies for constructing high-precision positioning systems and autonomous navigation that have low power consumption and high resistance to external influences.

2. Subject Area Overview
Currently, in science and practice, there are a large number of methods and technologies for positioning moving objects. Technologies include: GSM [2,3], UMTS [4,5], GPS [6,7], GLONASS [8-10], WLAN [11,12], Bluetooth [13-16], Bluetooth Low Energy [13-16]. Methods include: Received signal strength indicator (RSSI), Time of Arrival (ToA), Angle of Arrival (AoA), Incremental algorithm (IA), Geometric algorithm (GA), Enhanced Observed Time Difference (E-OTD), Uplink Time Difference of Arrival (U-TDoA), Observed Time Difference of Arrival (OTDoA), Cell ID, Timing Advance based positioning (TA).

According to the studies given in the [16], the possibilities of using the technologies and methods discussed can be represented in the form of Figure 1.

![Figure 1](image_url)

**Figure 1.** The possibility of using technologies and positioning methods.

Additionally, the analysis presented Bluetooth Low Energy technology. It is on the basis of the presented technology that the development of an algorithm for autonomous positioning of a moving object is proposed. A detailed description of the technology and the reasons for choosing are given by the authors in the work [15].

3. Development of an Algorithm Positioning a Mobile Object

3.1. BLE-beacon Work Description
The initial practical application of BLE beacons was to determine the proximity to any object on the territory of the enterprise. For example, to a specific storage location. Thus, when installing a BLE-beacon directly in the storage area, during the loading / unloading operation, it is possible to determine from which storage area a particular product was taken.

To solve this problem, it was planned to use BLE beacons based on the nRF51822 chip. In order to determine which beacon is in sight, it is proposed to use the iBeacon data format. The iBeacon format assumes the indication in the transmitted packet of the beacon identifier (Proximity UUID) and indicators of the relationship to any set of beacons (Major and Minor). The iBeacon format is clearly presented in the form of table 1.
3.2. **Hardware Overview**

After choosing a posing technology, the main issue is the selection of equipment that operates on the basis of the selected technology. In the case of BLE technology, there are a large number of manufacturers on the market. When choosing the equipment, the following analogues were considered: nRF51822, FSC-BP104, MyBeacon2016. The main criterion for choosing BLE beacons Comparative characteristics are shown in Table 2.

**Table 2. Comparative characteristics of BLE beacons.**

| Appearance | nRF51822 | FSC-BP104 | MyBeacon2016 |
|------------|----------|-----------|--------------|
| Specification | Bluetooth | 4.2 | 5.0 | 4.2 |
| Range of action | Up to 15 meters | Up to 100 meters | Up to 15 meters |

The team has at its disposal 3 beacons based on the nRF51822 chip and 15 FSC-BP104 beacons.

3.3. **Algorithm for Building Sensor Networks from BLE Beacons**

Formulation of requirements for sensor networks based on Bluetooth Low Energy beacons (BLE-beacons) should begin with the choice of positioning methods. In the presence of a large number of BLE beacons, one of the maximum positioning methods is the Received Signal Strength Indicator (RSSI) method [15,16]. This approach is used by leading companies, as mentioned in the analytical review. The essence of the approach lies in the transmission of the BLE beacon identifier, and the reading equipment itself determines the signal level, and, according to the preset standards, determines the conditional distance from the beacon (close / far).

To organize positioning, it is proposed to use the trilateration method, which involves the use of 3 readings from BLE beacons to determine the position relative to them. The use of this approach will make it possible to reduce the cost of the design of the beacons themselves as much as possible due to the absence of computing devices and reduce their power consumption due to low activity (transmission of the identifier every few seconds).

To use the trilateration method, the following requirements can be imposed on sensor networks:

- it is necessary to know in advance the size of the controlled premises or territory;
- it is necessary to calculate the displacement of the beacons relative to the plan of the premises or territory to determine the values of b, c, d (Figure 2);
- it is necessary to determine the number of beacons and their location in the controlled room based on its size and radio signal propagation environment.

**Table 1. Format iBeacon.**

| Byte number | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9-24 | 25 | 26 | 27 | 28 | 29 |
|-------------|---|---|---|---|---|---|---|---|---|-----|----|----|----|----|----|
| Default value | 0x02 | 0x01 | 0x06 | 0x1a | 0x40 | 0x02 | 0x15 |
| Note | Length Type Value Length Type Manufacturer or ID SubType Length SubType Proximity UUID Major Minor Power Signal |

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3.4. Development of an Algorithm for Determining the Movement of a Mobile Object

In order to organize automatic tracking of a moving object in a controlled area, it is necessary to mark it in advance using low-power radio beacons. It should be taken into account that for a more accurate determination, the distance between adjacent radio beacons should be approximately the same (s) as shown in figure 3. Thus, the distance s also becomes the beacon reach.

The distance s is selected based on the characteristics of the premises and the required positioning accuracy. Experimental studies with radio beacons based on the Bluetooth 5.0 specification show that in order to achieve the maximum positioning accuracy (error value of about 5-15 centimeters), the distance s should be in the range from 1 to 4 meters. In cases where the positioning accuracy can be neglected (the error is about 50 centimeters), the distance s can be from 1 to 50 meters.

With such a marking of the controlled area, the threshold for the presence of a mobile object in the broadcasting area of the current beacon can be calculated by the formula:

\[ p = \frac{1}{N} \sum RSSI_b \]
where \( N \) is the total number of readings for determining the threshold value, RSSIs is the value of the RSSI signal level at a distance \( s \).

Let all the values of the RSSI signal levels of each beacon before the objects moved through the monitored territory are entered in the log \( L \) and all known moving objects are entered in the list \( M \). Then the position of the current moving object in relative coordinates can be calculated by the formula:

\[
\begin{align*}
    x_{\text{Relative}} &= \frac{r^2 - r_j^2 + d_{i,j,k}^2}{2c_{i,j,k}} \\
    y_{\text{Relative}} &= \frac{r^2 - r_k^2 - x^2 + (x - d_{i,j,k})^2}{2c_{i,j,k}}
\end{align*}
\]

where \( r \) is the calculated distance from the radio beacon to the moving object, \( i, j, k \) are the indices of the “nearest” (with the highest RSSI signal level) radio beacons, \( b, c, d \) are the offsets along the coordinate axes of the corresponding relative coordinate plane \( i, j, k \) ...

The beacon indices \( i, j \) and \( k \) are found over a certain period of time \( t \), which depends on the response time of the beacons. The recommended \( t \) value is between 3 and 5 beacon responses:

\[
i = \max(L^<i>)
\]

\[
j = \max(L^<j>)
\]

\[
k = \max(L^<k>)
\]

where \( t \) is the time period for which it is necessary to obtain data on the signal levels, \( L_j \) is the log of the values RSSI signal levels of each beacon to the object moved through the monitored area without value \( i \), \( L_k \) is the log of the values of the RSSI signal levels of each beacon to the object moved across the monitored area without the values of \( i \) and \( j \).

The obtained coordinates \( (x_{\text{Relative}}, y_{\text{Relative}}) \) are relative and indicate the position of the object relative to the \( i, j, k \) plane. In order to obtain absolute coordinates relative to the zero coordinate of the room itself, it is necessary to project the relative coordinates onto the absolute plane. In the figure 3, the origin is at point \( (0,0) \). Based on the fact that the controlled room is divided into squares, it is necessary to know the index of the beacon, which is closest to the origin. Having received its offset, you can convert the relative coordinates to absolute. Let the beacon offset be denoted as \( (m, n) \), where \( m \) is the OX offset and \( n \) is the OY offset. Then the translation of relative coordinates to absolute can be done using the formula:

\[
\begin{align*}
    x_{\text{Absolute}} &= x_{\text{Relative}} \times m \times S \\
    y_{\text{Absolute}} &= y_{\text{Relative}} \times n \times S
\end{align*}
\]

The resulting coordinates \( (x_{\text{Absolute}}, y_{\text{Absolute}}) \) are absolute coordinates indicating the position of the moved object in the controlled area.

4. Experimental Research

In order to check the adequacy of the proposed algorithm, an experiment was carried out. A sensor network of 15 BLE beacons was created in a room measuring 5 by 10 meters (Figure 4). They were all located based on the recommendations outlined above. The distance between adjacent beacons is 2.5 meters.

![Figure 4](image-url)
For 10 minutes, a mobile device (a smartphone with its own preinstalled software [17]) moved around the perimeter of the room, which read the RSSI signal levels from each beacon. The received data was transmitted to the server for further processing according to the previously described algorithm. The results of positioning a mobile device are shown in Figure 5.

![Figure 5. Results of experimental studies.](image)

Based on the experiment, it can be concluded that the developed algorithm allows positioning a moving mobile device in real time with an accuracy of 5-73 cm. The use of additional tools for clarifying the positioning results can improve this result.

5. Conclusion
In the course of research on the automatic positioning of a mobile device in a room based on data from a sensor network of BLE beacons, an algorithm for positioning a moving object was proposed by modifying the multi-lateration method. The interaction of the mobile device and the sensor network is proposed to be carried out via a Bluetooth communication channel of specification not lower than 5.0 by obtaining the values of the RSSI signal levels of each radio beacon. The room has its own absolute coordinate plane. According to the multilateration method, each triplet of beacons forms its own relative coordinate plane. The developed algorithm also considers the issue of converting relative coordinates to absolute ones. At the end of the study, a description is given of an experimental study on positioning a mobile phone in a 5 by 10-meter room.

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