ТЕХНИЧЕСКИЕ НАУКИ
И ТЕХНОЛОГИИ

IT, АВТОМАТТАНДЫРУ ЖӘНЕ БАСҚАРУ,
МАТЕМАТИКАЛЫҚ КОМПЬЮТЕРЛІК МОДЕЛЬДЕУ
IT, АВТОМАТИЗАЦИЯ И УПРАВЛЕНИЯ,
МАТЕМАТИЧЕСКОЕ КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ
IT, AUTOMATION AND CONTROL, MATHEMATICAL COMPUTER MODELING

DOI 10.51885/1561-4212_2023_1_99
IRSTI 50.09.45

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RSSI-BASED INDOOR POSITIONING USING IBEACON AND INERTIAL NAVIGATION

IBEACON ЖӘНЕ ИНЕРЦИЯЛЫҚ НАВИГАЦИЯНЫ ҚОЛДАНУ АРҚЫЛЫ RSSI НЕГІЗІНДЕГІ ІШКІ ПОЗИЦИЯЛАУ

ПОЗИЦИОНИРОВАНИЕ В ПОМЕЩЕНИИ НА ОСНОВЕ RSSI С ИСПОЛЬЗОВАНИЕМ IBEACON И ИНЕРЦИАЛЬНОЙ НАВИГАЦИИ

Abstract. *This article presents an indoor navigation system and the purpose of this study is to create and test a high-precision indoor positioning system using Bluetooth beacons and inertial navigation system sensors. The system determines the location of a mobile object by combining information from an inertial navigation system sensor with RSSI (Received Signal Strength Indication) indicators. The navigation system uses two types of information: Inertial navigation system data is more accurate in the short term, but the error increases over time, and RSSI position estimates have limited positioning error. It is anticipated that positioning accuracy can be significantly improved by using filtering and data smoothing methods by combining RSSI data from Bluetooth beacons with data from INS sensors.*
Keywords: *Indoor navigation, RSSI, IBEACON, inertial navigation, smoothing and filtering of navigation data.*

Аңдатпа. *Мақалада ішкі навигациялық жүйе ұсынылған және бұл зерттеудің мақсаты Bluetooth маяктары мен инерциялық навигациялық жүйенің сенсорлық технологиясын қолдана отырып, жоғары дәлдіктегі ішкі позициялау жүйесін құру және сынау болып табылады. Жүйе инерциялық навигациялық жүйенің сенсорынан ақпаратты RSSI индикаторларымен (қабылданған сигнал деңгейінің көрсеткіші) біріктіру арқылы мобильді объектінің орналасқан жерін анықтайды. Навигациялық жүйе ақпараттың екі түрін қолданады: инерциялық навигациялық жүйенің деректері қысқа мерзімде дәлірек болады, бірақ уақыт өте келе қате көбейеді, ал pиps позициясын бағалауда позициялау қатесі шектеулі. Bluetooth маяктарынан RSSI деректерін сенсорлық деректермен біріктіру арқылы деректерді сүзу және тегістеу әдістерін қолдану арқылы позициялау дәлдігін айтарлықтай жақсартуға болады деп күтілуде.*
Түйін сөздер: *ішкі навигация, RSSI, IBEACON, инерциялық навигация, навигациялық деректерді деңгейлестіру және сүзу*
Аннотация. *В статье представлена внутренняя навигационная система, и целью данного*

исследования является создание и тестирование высокоточной внутренней системы позиционирования с использованием Bluetooth-маяков и датчиков инерциальной навигационной системы. Система определяет местоположение мобильного объекта путем объединения информации от датчика инерциальной навигационной системы с индикаторами RSSI (Индикация уровня принятого сигнала). Навигационная система использует два типа информации: данные инерциальной навигационной системы являются более точными в краткосрочной перспективе, но ошибка увеличивается с течением времени, а оценки положения RSSI имеют ограниченную ошибку позиционирования. Ожидается, что точность позиционирования может быть значительно улучшена за счет использования методов фильтрации и сглаживания данных путем объединения данных RSSI от маяков Bluetooth с данными от датчиков INS.

Ключевые слова: *внутренняя навигация, RSSI, IBEACON, инерционная навигация, сглаживание и фильтрация навигационных данных.*

Introduction. Currently, the problem of indoor navigation has become very relevant for researchers, since knowing the location of an object (vehicle, robot) is valuable information for many applications.

In addition, interest in indoor navigation is heightened by the fact that some technologies developed for the external environment cannot be used inside a building; for example, GPS (Global Positioning System) navigation is less accurate in buildings as satellite signals are weakened by roof, floor or wall obstructions.

GPS technology can be adapted to work in buildings, but has major limitations such as longer measurement times, lower accuracy, higher prices.

The purpose of this study is to create an indoor navigation system using Bluetooth beacons, INS sensors and experimental verification. This study is a continuation of work [1,2].To improve positioning accuracy, methods of smoothing, filtering data received from beacons and INS sensors are proposed, and it is assumed that the positioning accuracy can be significantly improved if filtering and smoothing methods of received data are used in addition to the RSSI data of the Bluetooth Beacon.

Related Work. Khanh T.T. et al. in [3] proposes a cloudlet based on cloud computing. The system uses a two-tier cloud: the core cloud is used to store all information about objects, such as global position and status, and the cloudlet stores all specific information about objects. Hosted on a mobile platform, the Raspberry Pi3 calculates route path, track information and location estimates. In their opinion, the implementation results demonstrated the effectiveness of this approach.

The authors of [4] proposed and developed a unique hybrid approach based on fingerprinting to eliminate the shortcomings of existing methods. Therefore, the accuracy of this one-of-a-kind algorithm is 2.52m in an office and 3.13m in an underground mine. They also compared the proposed hybrid algorithm with a weighted K-nearest neighbor (WKNN). On the other hand, WKNN has an accuracy of 4.01 m in the office and 4.33 m in underground mining.The authors of [4] proposed and developed a unique hybrid approach based on fingerprinting to eliminate the shortcomings of existing methods. Therefore, the accuracy of this one-of-a-kind algorithm is 2.52m in an office and 3.13m in an underground mine. They also compared the proposed hybrid algorithm with a weighted K-nearest neighbor (WKNN). On the other hand, WKNN has an accuracy of 4.01 m in the office and 4.33 m in underground mining.

The wireless signal is unstable in an inhomogeneous internal environment, and this affects the accuracy of RSSI-based location methods. In order to mitigate the impact caused by fancy RSSI values, some measures are applied in the article [5]. Firstly, the cosine value between the real-time and fingerprint vectors made up of RSSI is an effective indicator for localizing probability. Then the calculation and characteristics of the cosine value of RSSI vectors (RVCV) are discussed. As for the RVCV ranking, the number of RVCVS used for positioning with iteration changes and gradually decreases, which is called K and is determined by the 95% confidence interval for the standard normal Gaussian distribution in this article. Secondly, the average value of the neighborhoods used for ranking RVCV has been adopted and developed. Further, in combination with the K parameter, a new method of RVCV localization with a K rating for indoor positioning is proposed. Finally, experiments are conducted, and the correct localization rate between K-ranking in nine cases and WKNN(k = 4) is compared a total of 4,200 times with different error intervals. Their results demonstrate that the positioning accuracy of the RVCV algorithm with K-ranking can improve the accuracy of localization indoors.

The purpose of the article [6] is to implement a localization system to determine the user's location in a room using the most well-known data transmission technologies, Wi-Fi and Bluetooth Low Energy. In addition, it examines the performance of these two transmission technologies in terms of latency and accuracy at different numbers of bindings using RSSI and fingerprint-based trilateration methods.

Chen Zhenghua et al. In the article [7] propose an indoor localization system based on inertial sensors with iBeacon periodic adjustment. A Pedestrian Dead Reckoning (PDR) model is used, and data from iBeacon is used to calibrate the PDR approach drift. The experimental results demonstrated the effectiveness of the proposed approach.

In [8,9], an approach based on iBeacon and PDR is also proposed. In addition to iBeacon and PDR, a special fingerprint method is used. The approach is implemented in an Android smartphone. The results show that the fusion technique can improve the accuracy of real-time trajectories and reduce the effects of inaccurate starting positions, systematic drift, and attitude noise. The iBeacon based positioning method provides basic accuracy, while the PDR method smooths trajectories in real time and increases their continuity.

In addition, the works [10-13] for solving the problems of internal navigation were considered. to improve the accuracy of internal navigation, they recommend using several sources.

Materials & Methods. In this paper, navigation is based on iBeacon beacons and the localization method is based on a trilateration algorithm that uses distances calculated from RSSI information as input data. The environment can interfere with radio signals (radio interference, reflections), so the accuracy of the RSSI method is lower than others. The RSSI data was combined with the INS sensor data to provide a system that provides the required positioning accuracy.

The positioning algorithm was carried out using a mobile node equipped with an Atmega328 microcontroller and additional INS sensors, and a fixed iBeacon node used as a beacon (fixed reference point). The navigation system uses reference points-iBeacon nrf51822 (Figure 1).

Figure 1. iBeacon Module nrf51822

In this paper, a 2D coordinate system is considered, in which iBeacon modules are arranged in the form of a quadrangle (Figure 2).

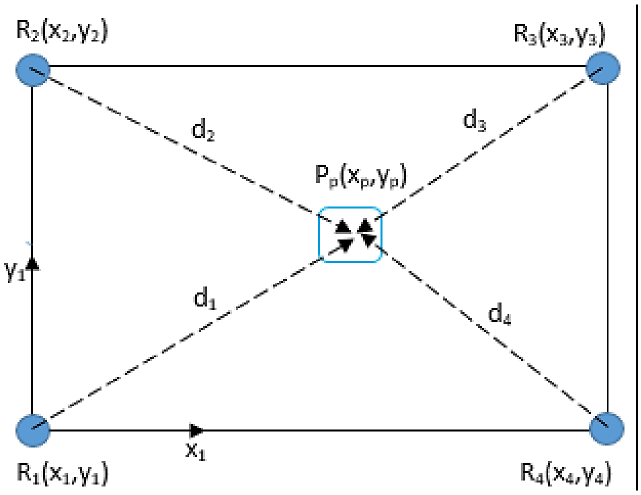

Figure 2. The distance based on RSSI positioning

The mobile node consists of the following hardware components: an ATmega microcontroller, a Bluetooth HC05, an INS module (MPU 6050 accelerometer) and a 2-cell lithium polymer battery. The system operation diagram is shown in Figure 3.

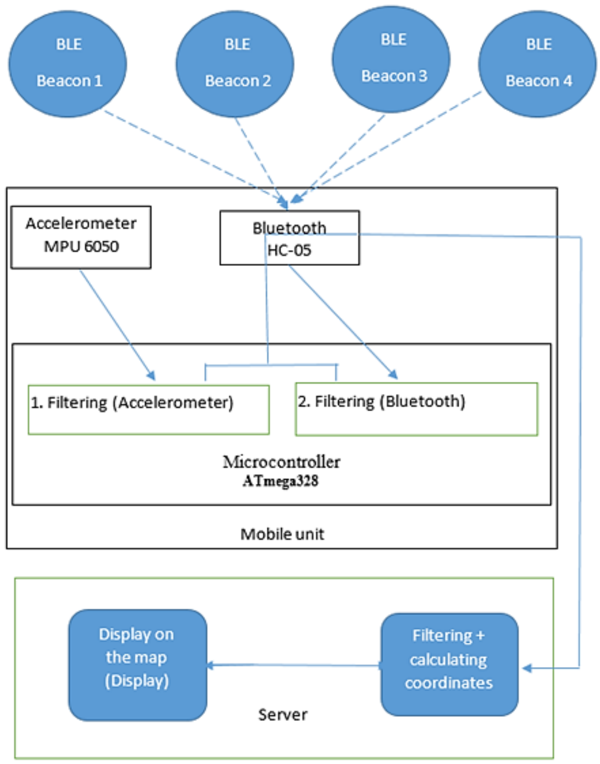

Figure 3. System operation diagram

To identify the location of an object *P* the follow hypothesis is required [1]:

a) iBeacon $(R_1,...,R_4)$ major nodes are fixed;

b) $(x_i, y_i), i = \{1, \ldots 4\}$ coordinates are fixed;

c) the P node receiver has to receive data from 4 fixed nodes.

The distance between the positioning node P and the object can be defined via RSSI value [1]:

$$P_r(d) = P_0 + 10 n_p \, log_{10}(d_0 / d) \quad (1)$$

P_r – signal strength at a distance of nodes d;
P_0 – signal strength obtained at a distance of nodes d0;
n_p – distribution constant of a signal.
Equation (1) leads to:

$$P_r(d) = -10 n_p \, log_{10}(d) + A \quad (2)$$

The distance d can be obtained from the follow relation:

$$d = 10^{A - P_r / 10 n_p} \quad (3)$$

The distance d_i between the receiving node $P(xp,yp)$ and major nodes $R(xi,yi)$ is expressed through the follow relation:

$$d_i^2 = (x_i - x_p)^2 + (y_i - y_p)^2 \quad (4)$$

The equation (4) may be formed in this way:

$$d_i^2 = (\, x_i^2 + x_p^2 - 2x_i x_p + y_i^2 + y_p^2 - 2y_i y_p \quad (5)$$

At this point the equation (5) is concerned with another control point k:

$$d_k^2 = x_k^2 + x_p^2 - 2x_k x_p + y_k^2 + y_p^2 - 2y_k y_p \quad (6)$$

If we substract equation (5) from equation (6), then we obtain the following relation:

$$d_i^2 - d_k^2 + x_k^2 + y_k^2 - x_i^2 - y_i^2 = 2(x_k - x_i)x_p + 2(y_k - y_i)y_p \quad (7)$$

If we consider $i = 1$ and the variable index $k = \{2, \ldots 3\}$, then we obtain the following system of equations:

$$\begin{bmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) \\ 2(x_4 - x_1) & 2(y_4 - y_1) \end{bmatrix} \begin{bmatrix} x_p \\ y_p \end{bmatrix} = \begin{bmatrix} d_1^2 - d_2^2 + x_2^2 + y_2^2 - x_1^2 - y_1^2 \\ d_1^2 - d_3^2 + x_3^2 + y_3^2 - x_1^2 - y_1^2 \\ d_1^2 - d_4^2 + x_4^2 + y_4^2 - x_1^2 - y_1^2 \end{bmatrix} \quad (8)$$

The coordinates (xp, yp) of the node P can be found by solving the system of equations (8).

The location of the nodes obtained using RSSI localization is not accurate since the radio signal may be distorted by some factors which may be found in enclosed spaces. To get the required accuracy of location data obtained on the basis of RSSI information is connected to the location data of the INS module. These two sources of information are characterized by complementary properties. INS data providing positioning and orientation is more accurate in the short term but errors, due to deviations affecting the accelerometer and gyroscopic sensors, begin to increase over time. Unlike INS the distance, calculated with the usage of RSSI information, has limited error in the long term but in the short term has low accuracy.

There are plenty of methods, which can be used for RSSI and INS data integration. As a method of data combining the Extended Kalman filter (EKF) is chosen because this method can be easily used for nonlinear system [14, 15].

The following is a brief description of the EKF used to assess the state of a discrete dynamic system:

$$x_k = f(x_{k-1}, u_k, w_{k-1}) \\ z_k = h(x_k, v_k) \quad (9)$$

xk – state vector,
uk – control input,
wk – process noise,
zk – system output,
vk – measuring noise.

The algorithm consists of two repeating phases: forecasting, where the next state of the system is predicted and correction, where, based on the measurements obtained at the output of the system, amendments are made to the state of the predicted system [8].

In the “prediction” phase $\hat{x}_k^-$ (a priori assessment) and $\hat{P}_k^-$ (error covariance prediction) can be obtained from the following relations:

$$\hat{x}_k^- = f(\hat{x}_{k-1}, u_k, 0) \\ P_k^- = A_k P_{k-1} A_k^T + W_k Q_{k-1} W_k^T \quad (10)$$

Ak – The Jacobi matrix f is relatively to x, determined by the following relation:

$$A_k = \frac{\partial f}{\partial x}(\hat{x}_{k-1}, u_k, 0) \quad (11)$$

Wk – the Jacobi matrix f is relatively to w, determined by the following relation:

$$W_k = \frac{\partial f}{\partial w}(\hat{x}_{k-1}, u_k, 0) \quad (12)$$

Qk – The noise covariance matrix *wk*,
Pk – the noise covariance matrix *vk* at the system output.

In the “correction” phase the subsequent state of the system can be calculated using the following relationships:

$$\hat{x}_k = f(\hat{x}_k^-) + K_k(z_k - h(\hat{x}_k^-, 0)) \quad (13)$$

Kk – the Kalman strength, which is determined by the following relationship:

$$K_k = P_k^- H_k^T (H_k P_k^- H_k^T + V_k R_k^- V_k^T) \quad (14)$$

The algorithm of Extended Kalman Filter is presented in Figure 4.

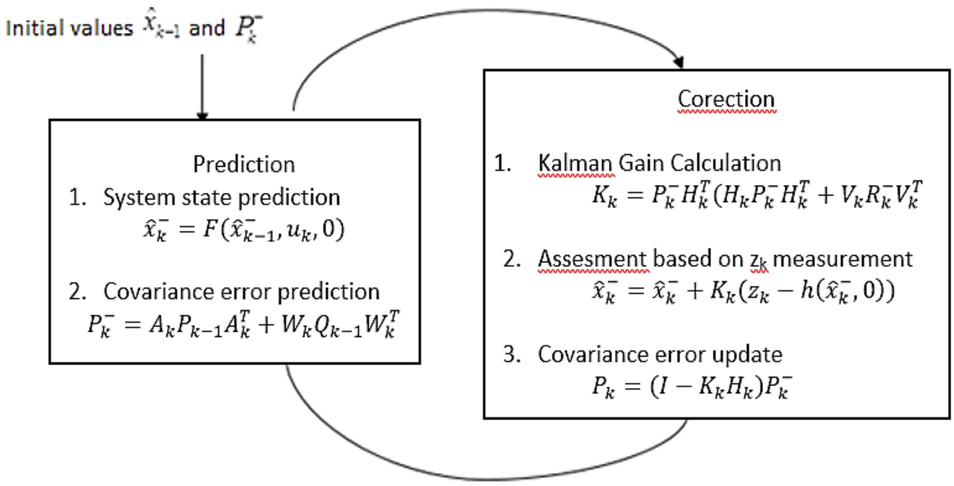

Figure 4. Extended Kalman Filter algorithm

Consider the state vector of the dynamic model, which is determined by the system coordinates and velocities along the *x, y* axes. The transition of a system from one state to another can be shown as follows:

$$\begin{bmatrix} x \\ y \\ u \\ v \end{bmatrix}_{k+1} = \begin{bmatrix} 1 & 0 & T & 0 \\ 0 & 1 & 0 & T \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ u \\ v \end{bmatrix}_k \tag{15}$$

From the previous section, we know that you can calculate the coordinates (*x, y*) using the RSSI method. For this reason, (*x, y*)T is assumed to be the original vector. The initial data of the system will be expressed as the following relationship:

$$z_k = \begin{bmatrix} x \\ u \end{bmatrix}_k = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ u \\ v \end{bmatrix}_k \tag{16}$$

one can easily determine the matrices of passage and measurement of the dynamic system (15) and (16):

$$A_k = \begin{bmatrix} 1 & 0 & T & 0 \\ 0 & 1 & 0 & T \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad H_k = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \tag{17}$$

T – the approximate period.

Suppose the state of an extended Kalman filter means an error in the state vector of a dynamical system. The Kalman filter dynamics is as follows:

$$\begin{bmatrix} \partial x \\ \partial y \\ \partial u \\ \partial v \end{bmatrix}_{k+1} = A_k \begin{bmatrix} \partial x \\ \partial y \\ \partial u \\ \partial v \end{bmatrix}_k \quad (18)$$

Equation (18) indicates that we can assume the error state of the dynamical system a priori.

Results. The positioning algorithm was carried out using the Arduino Uno mobile node equipped with additional INS sensors and the iBeacon stationary node used as a beacon (fixed reference point).

When navigation system implementation four reference points are used – nrf51822 iBeacon (consists of a module and a battery).

The mobile node consists of the following hardware: Arduino Uno microcontroller board, IMU module (inertial measurement unit), and a lithium-polymer 2-cell battery.

During the experiment, the relationship between the RSSI value and the distance of the mobile nodes with fixed reference points was determined. In order to find this relationship, the average RSSI values were measured in several places of the room. The results are shown in table 1.

Table 1. RSSI

Pops(m)	Y_pos(m)	Distance (m)	RSSI
1	1	1.41	-52.05
2	2	2.79	-54.97
3	3	4.24	-57.08
4	4	5.65	-58.81

Using experimental data, the following relationship between RSSI and distance was determined:

$$RSSI(d) = -11.85 log_{10}(d) - 48.82 \quad (19)$$

In addition, the relationship between the RSSI value and the distance can be displayed as a graph in Figure 5.

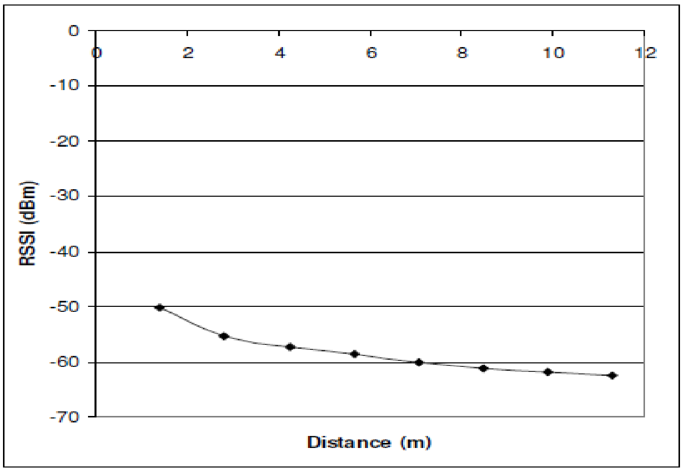

Figure 5. Relationship between distance and RSSI values

The data merging algorithm has been tested in the Matlab Simulink environment. Mobile nodes were considered movable on a plane with constant acceleration. The speed and state of the object's movement are calculated using the following differential equations:

$$\begin{aligned} \dot{u} &= a_x \quad \dot{x} = v \\ \dot{v} &= a_x \quad \dot{y} = u \end{aligned} \tag{20}$$

For accelerometer, used in INS, the following measurement ratios are provided:

$$\begin{aligned} a_{x\_imu} &= a_x + w_{acc} \\ \dot{u} &= a_x \end{aligned} \tag{21}$$

wacc – the white noise of a sensor with dispersion *σ2=2mg*

It was taken into account that the location, which was determined by RSSI indicators, as described in equation (22), is affected by the white noise with a dispersion of 2 m and a zero-average value.

$$\begin{aligned} x_{RSSI} &= x + w_{RSSI} \\ y &= y + w_{RSSI} \end{aligned} \tag{22}$$

Figure 6 shows a block diagram of Simulink, a Kalman filter, combining data obtained from RSSI and IMU submodules.

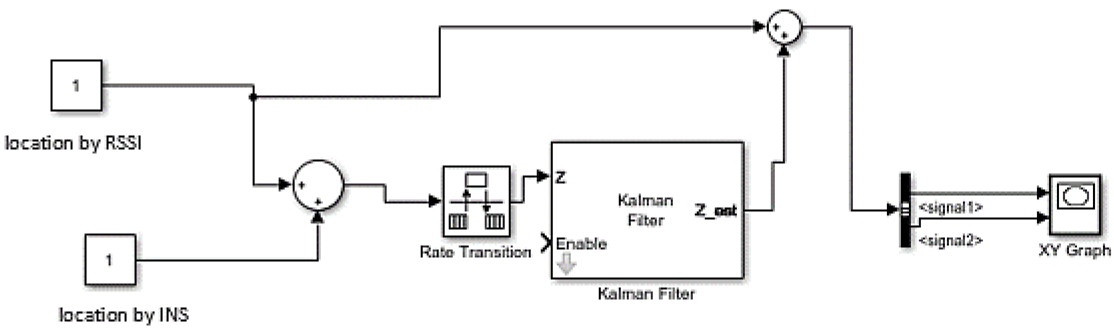

Figure 6. Implementation in the MATLAB SIMULINK environment

Figure 7 shows that algorithm of localization, implemented using only RSSI values, has low accuracy; max distance between calculated area and exact one is 4 meters.

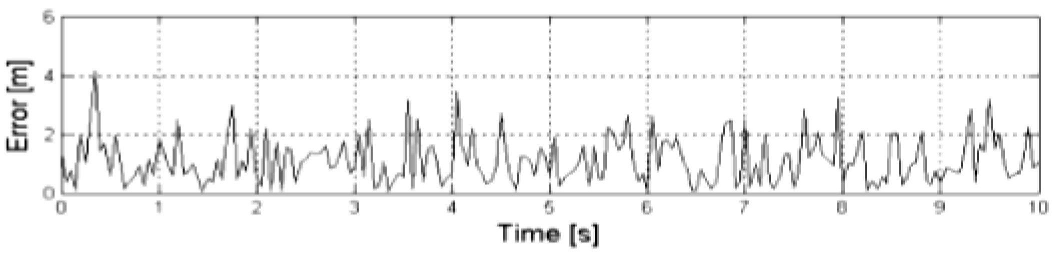

Figure 7. RSSI error assessment for location

The result of proposed location algorithm can be seen in Figure 6. The accuracy of calculated position is increased by using two sources of information (RSSI and INS).

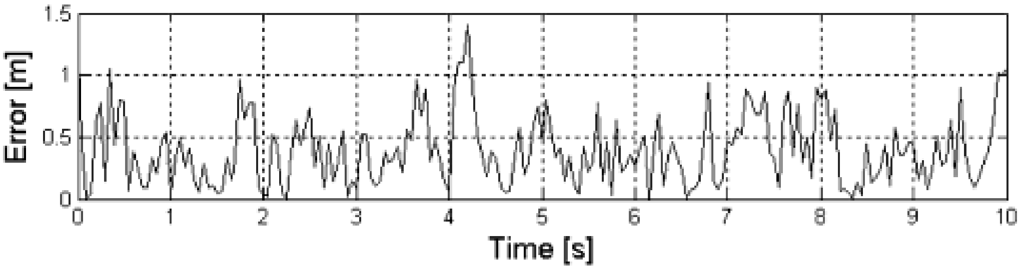

Figure 8. Error assessment of proposed system for location

*Discussion***.** In the course of the experiment, it was revealed that if the data from the INS are additionally used to the RSSI data of the Bluetooth beacon and the methods of filtering and data smoothing are applied, then an acceptable position determination accuracy can be achieved. Unlike known approaches, no signal map and smartphone sensors are used. The use of filtering methods and data smoothing has improved the accuracy of determining the location in the internal positioning system.

Conclusions. Location based on received signal strength is the primary method for determining the location of objects in wireless sensor networks. However, RSSI-based methods have low accuracy. This article describes the navigation systems based on Bluetooth and INS, presents the results of experiments to determine the location of a mobile node using indicators of the signal levels of a Bluetooth device. An extended Kalman filter was used to improve the accuracy of location detection.

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