Liable Bluetooth tracking technology for enhancement of location-based services

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Abstract. In recent years, user demand for location-based services has become increasingly urgent. Currently, the main internal positioning technologies include UWB (Ultra-Wide Band), RFID (Radio Frequency Identification), ultrasonic and inertial navigation, optical positioning, Wi-Fi, etc. This article briefly discusses the use of Bluetooth beacons for location, indoor navigation and related algorithms.

1. Introduction
The local positioning and person tracking is an emerging field that has its application in industry, medicine, public services. The great number of positioning are practical and considered for the purpose [1], however wireless communication technologies is the most frequent option [2].

Selection of wireless positioning technology of the transmitting signal in the room includes a network, a mobile terminal and a positioning mode. Wireless positioning in the room is mainly carried out using sensors of a network system. Mobile terminals mainly include smartphones, smart terminals and laptops. The method of posing depends on the current conditions in the room.

Bluetooth technology is widely used in the Internet of Things (IoT), which is the main device when used in low power consumption (LE) mode for beacons, water-free sensors, asset tracking systems, remote controls, performance monitors and alarm systems.

This article will discuss the application of positioning technology using Bluetooth beacons and the implementation of appropriate navigation algorithms.

Beacons with Bluetooth Low Energy (BLE) technology when approaching a client with Apple iPhone (iOS) or Android, display a standard notification on the smartphone or launch a mobile application.

2. Scope of Bluetooth Beacons
Any Bluetooth mobile phone can be used to detect and view BLE devices. One of the most useful beacon services is that they can be used for advertising wherever there are people: in shopping centers, shops, parks and even at events. To use it, there must be a beacon-compatible device [2].

The use of wireless technology to get closer is not news, but with the introduction of low-power Bluetooth features in 2010, beacons are now deployed on a wide scale. This is an important and significant technology for the IoT [3].
Bluetooth transmitted information can be environmental data (temperature, atmospheric-spherical pressure, humidity, etc.), microlocation data (asset tracking, retail, etc.) or orientation data (acceleration, rotation, etc.). These devices are used to transmit data using Bluetooth Low Energy [4] signals.

3. **Bluetooth - beacons of different manufacturers**

Unlike GPS, beacons can be used to accurately locate the room. There were many applications, including internal navigation, location-based marketing, location-based customer service, customer search, and personalized help. Since the standard Bluetooth LE is used in May, it is well supported on both Android and iOS.

Bluetooth beacons are used to transmit data to neighboring devices. This technology allows devices to perform actions when the device is close to the beacon. Google Eddystone and Apple iBeacon are Bluetooth beacons.

Currently, there are three main market standards for beacons: Apple's iBeacon was introduced in 2013, Network Radius's AltBeacon standard in 2014, and Google's Eddystone appeared in 2015 [2].

**Standard iBeacon.** Various hardware implementations are iBeacons available on the market in the range of $5 to $30. All these iBeacons have different default settings for iBeacon advertising and transmission frequency. One of such well-known software implementations is available on Android.

![Figure 1. iBeacon](image1.png)

**The Eddystone standard** is capable of supporting four types of packages: Eddystone-URL, Eddystone-UID, Eddystone-EID, Eddystone-TLM. The contents of the URL package are of pe-belt length and apply unique compression schemes to reduce the size of the URL to a limit of 17 bytes. The UID packet has a unique 16-byte beacon ID with a 10-byte namespace. The EID Pa-Ket has a short-lived identifier for May-Ks requiring a higher level of security. The TLM package broadcasts telemetry data about the SA beacon (battery level, time since inclusion, amount of advertising, etc.).

Using the Eddystone Standard, Google developed the Google Nearby service, which allowed Android users to receive beacon notifications without installing any third-party applications. "Google nearby" was installed on Android in 2018.

![Figure 2. Eddystone](image2.png)
4. Energy efficiency
To implement the system, beacons (or devices that simulate their operation) are needed directly. By Bluetooth Low Energy Beacon we will mean mini-turf battery devices based on BLE, for the transfer of a small amount of static or dynamic information. Such devices are often designed for continuous operation for several years, which is provided by BLE technology, which implies low power consumption, achieves a reduction in data transmission time and plunges the device into sleep mode between packet transmission [7].

Perry Lee, in his book The Architecture of the Internet, argues that the effect of frequent advertising signs affects the life of the lighthouse battery. As a rule, batteries in beacons are lithium-ion cells. CR2032 Cites as an argument the analysis of Aislelabs research (under the international Creative Commons Attribution 4.0 license), in the report "Hitchhiking Guide to Equipment iBeacon: a comprehensive report of Aislelabs. Web March 14, 2015 (https://www.aislelabs.com/reports/beacon-guide/), "the report describes how to analyze the battery life of some ordinary beacons and how to change their re-claw interval (100 ms, 645 ms and 900 ms). They also used different batteries with increased spare power.

The results show that the average life varies between 10 and 15 months, a minimum of 5, a maximum of 36 months depending on the set of micro-schemes, but also, more importantly, due to the advertising interval. Along with the advertising interval, power, without condition, affects the total battery life, but also the number of frames transmitted.

5. Location algorithms
There is a family of collaborative filtering algorithms for analyzing different opinions and views of users and developing personal recommendations - Slope One.

The received signal strength indicator (RSSI) can be translated into between beacons by theoretical or empirical models of radio wave propagation. With openly [6]:

\[ L(d) = L_{FS} + 10n \log\left(\frac{d}{d_0}\right) \]

where
\[ d_0 = 1m. \]

\( L_{FS} \) - free space loss at a distance \( d_0 \)

\( n \) – factor depending on the type of space, the number of obstacles and their material.

The parameter is usually specified by the beacon manufacturers themselves. Parameter \( n \) is empirically determined.

To determine coordinates, location algorithms are used - approaches to solving location tasks based on the powers of signals sent by beacons [6].

Algorithms that can be used to determine customer coordinates are:

\[
\begin{align*}
X_0 &= \frac{1}{N} \sum_{j=1}^{N} X_j \\
Y_0 &= \frac{1}{N} \sum_{j=1}^{N} Y_j
\end{align*}
\]

where \( N \) is a number of beacons, \( X_j, Y_j \) are coordinates of beacons - Lateration.

The geometric approach is based on calculating the distances between the desired point and at least three more points (Figure 2), with the solution of a system of nonlinear equations. To calculate the coordinates of a custom device, one needs to solve the system of equations:
\[ r_j = \sqrt{(X_j - X_0)^2 + (Y_j - Y_0)^2} \]  

where \( r_j \) is the distance from the client device to the beacons.

To find the distances, a radio wave propagation model is used, which requires the calibration of parameters that depend on the characteristics of the environment:

\[ PL(d) = P_t - P(d) = PL(d_0)0 + n10 \log \frac{d}{d_0}, \]

where is the \( d \)-distance to the client device, \( PL(d) \) is the loss of signal power at distance \( d \), \( P_t \) is the transmitter power, \( P(d) \) is the signal power at the receiver at the distance \( d \), \( d_0 \) is the distance of 1 meter, \( N \) is the propagation factor of the signal in the medium.

The first two algorithms are simple to implement and require only knowledge of the location of beacons. However, their disadvantage was low performance, since signal power was not taken into account.

6. Kalman filter. Process and Evaluation

The Kalman filter uses a dynamic model (e.g., a physical law of motion), known control actions, and a plurality of sequential measurements to generate an optimal state estimate. The filter removes measurement noises (random bursts) and produces the result as taking into account the predicted results based on past measurements. The algorithm consists of two repeating phases: prediction and correction. On the first, the prediction of the state at the next moment of time is calculated (taking into account the inaccuracy of their measurement). On the second, the new information from the sensor corrects the predicted value (also taking into account the inaccuracy and noisiness of this information) [7]. The Kalman filter considers the problem of estimating the cost of a discrete time process, which can be characterized by a linear difference equation:

\[ x_k = Ax_{k-1} + Bu_{k-1} + W_{k-1} \]  

The evaluation also requires the measurement \( z \in R_m \) as follows:

\[ z_k = Hx_k + v_k \]  

The random value \( w_k \) represents the noise of the process, the error between the approach and the real process. Another random variable, \( v_k \), represents the noise of the rays, the error between the measurements \( Hx_k \) and the real value.

Both variables are considered independent of each other, Gaussian and white:

\[ p(w) \approx N(O, Q) \]
\[ p(v) \approx N(O, R) \]

In this general introduction, the covariance of processes of noise of \( Q \) and covariance, and covariance of noise of measurements of \( R \) are considered as constant on iterations. However, they can change at each step (each iteration).

Matrix \( A \), of dimension \( n \times n \), is a state transition model that relates a state.

In the previous time step \( k-1 \) with the state in the current step \( k \). The matrix of \( B \), dimension of \( n \times 1 \), is the operating model which connects the additional operating \( u \) entrance \( \epsilon u \in R1 \) with a state. The \( m \times n \) \( H \) matrix is a model of observation that connects co-standing with the measurement \( z_k \).

Two definitions are now entered.
The first one:
\[-\hat{x}_k^- \in \mathbb{R}^n\]
is a priori assessment of the state at step \(k\), given the knowledge of the process prior to step \(k\).

The second one is:
\[-\hat{x}_k \in \mathbb{R}^n\]
and relates to estimating a posterior state in step \(k\) given by measurement \(z_k\).

A priori and posteriori evaluation errors:
\[e^-_k = x_k - \hat{x}_k^-\]
\[e_k = x_k - \hat{x}_k\]

With these errors, the covariance of a priori estimation error and the covariance of posterior evaluation errors can be calculated accordingly as:
\[P^-_k = E[e^-_k e_-^T]\]
\[P_k = E[e_k e^T_k]\]

When you output equations for a Kalman filter.

The first step is to find equations that accrue calculating a posterior estimate \(\hat{x}_k\) as a linear combination of a priori score \(Z_k\) and the weighted difference between the actual measure and the prediction \(H\hat{x}_k^-\) of the measured calculated using a priori estimate of the state.
\[\hat{X}_k = \hat{X}_k^- + K(z_k - H\hat{x}_k^-)\tag{8}\]

The difference \(z_k - H\hat{x}_k^-\) is called innovation and measures the mismatch between the predicted measurement and observed measurement. If the new-maintenance is zero, this means that they are in full agreement, so the predicted measurement is ideal due to a priori assessment of the state, is also perfect.

Matrix \(K\), of dimension \(n \times m\), is a Kalman gain that minimizes covariance of aposteriori error \(R_k\).

The general expression \(K\) in the current time step \(k\);
\[k_k = p_c h'^{-1}(h p_k h'^{-1} + r)^{-1}\tag{9}\]

Considering this expression, some information about the behavior of the Kalman filter can be extracted [8]. The Kalman filter evaluates the process using feedback control. First, the filter evaluates the state of the process at a certain time and then receives feedback in the form of noise measurements. Given this, the equations can be divided into two groups: correction equations and prediction equations. The first of them determine the next time state estimates and covariance errors to obtain a priori estimates for the next time step.

7. Conclusion

The use of iBeacon beacons and Bluetooth Low Energy technology allows easy orientation with almost any mobile device in large buildings and rooms. The development of other uses of these devices was also promising, in particular, to facilitate the orientation of people with disabilities (blind), providing stores with new types of advertising to attract customers and others.

Therefore, there is a need to develop algorithms for processing and filtering incoming data from each beacon. The application of basic space position determination algorithms (triangulation and trilateration) to solve the problem of accurate positioning in a building using beacons is also relevant. Based on this study, it is possible to make a conclusion that today systems that implement positioning
functions in the premises are still developing. Manufacturers of such systems had successfully implemented their mobile application platforms. The most popular indoor positioning technology today is the 802.11 radio signal printing method.

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