Enhanced Indoor Navigation System with Beacons and Kalman Filters

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***Abstract*—Indoor positioning systems are used in a variety of applications from shopping malls and museums to subject monitoring and tracking. The reliability and usability of such systems are highly based on their accuracy as well as cost and ease of deployment. Although the Global Positioning System (GPS) is an accurate solution for outdoor use, it can not be used indoors. A popular approach is a wireless navigation system which makes use of Received Signal Strength Indicators (RSSI). However, signal propagation, as well as surrounding noise and a dynamic environment, can affect their performance. Recent advancements in Bluetooth Low Energy (BLE) devices and the introduction of small and inexpensive beacons can alleviate the problem. In this work, we introduce an indoor navigation system with BLE beacons. To measure system accuracy an Android application was developed to collect the signal. Moreover, a Kalman filter was also developed within the application to improve the accuracy. Experimental results showed improvement of systems accuracy in three square topologies. The Kalman filter improved the accuracy up to 78.9%. while the experiments also show a correlation between the overall accuracy and how close BLE beacons are to each other.**

***Index Terms*—Indoor Navigation System, BLE, Beacons, Kalman Filter, RSSI.**

I. Introduction

Every day more computer-based devices are connected to the Internet. Most of these devices have at least one sensing unit, creating opportunities for more direct integration between the physical world and computer-based systems. This is the idea behind the Internet of Things (IoT), a development of the Internet in which everyday objects have network connectivity, allowing them to send and receive data.

The increase in connectivity has led to an increased desire for micro-location and indoor navigation [1]. There is a growing demand in industry for more advanced interaction with their customers in an indoor environment, and such interactions require indoor navigation systems. Shopping and entertainment are some of the first industries to adopt these systems. Industry giants such as Target and Walmart have already begun implementing these systems in select locations [2]. As a result, there is a push to develop an indoor navigation system that improves on accuracy, cost efficiency, power consumption, and scalability over the current solutions available today.

Wi-Fi technology, using Received Signal Strength Indicator (RSSI) techniques, is a known method of providing indoor location services [3]. However, there are various downfalls in using Wi-Fi that does not constitute its use as a well-established solution [4]. The first issue with regards to Wi-Fi based navigation systems is its inaccuracy. With the vast amount of Wi-Fi channels and networks already in use in most indoor environments, there is a great deal of contention and noise in the environment, leading to degraded signals, hence the poor accuracy. In addition, Wi-Fi utilizes considerably more energy than alternate solutions, such as Bluetooth or Bluetooth Low Energy (BLE), requiring that access points be wired so that the lifespan of the indoor navigation network can be sustained. Similarly, the requirement of wired power sources means that any Wi-Fi based solution increases the complexity of deployment, and subsequently the scalability into new environments.

Recent research explores the use of BLE beacon hardware as a sensible means of implementing an indoor navigation system [5]–[8]. BLE beacons, or just beacons, are a low cost, small transmitting device that utilizes Bluetooth Special Interest Group's BLE technology. They can be used to implement positioning techniques similar to that of Wi-Fi, in that RSSI values are translated into distances. They implement a simple protocol, either Apple's iBeacon [9] or Google's Eddystone [10], which are specifically designed for BLE beacons, making their communication much more lightweight and simplistic. The current market also shows that there are multiple vendors of BLE beacon devices, providing customers with competitive choices that meet their requirements. The BLE technology significantly reduces the power consumption of the beacons compared to Wi-Fi, allowing the devices to be fully wireless. Some may even operate on solar power [11]. The reduction in power consumption, fully wireless capabilities, and low cost make beacons a practical and scalable method of implementing indoor navigation systems, however, challenges regarding Line Of Sight (LOS) and environmental interference are significant issues that need to be addressed.

In this paper, we introduce the development of a simple BLE beacon based indoor navigation model. Three topologies are explored in order to convey the feasibility of such systems; a 1×1 m, 2×2 m, and 6×6 m geo-fence was created using 4 Gimbal Series 21 BLE beacon devices. The relative position to all 4 beacons in four defined positions was obtained in order to understand and compare each topology. The navigation model utilizes a Google Nexus 5 running Android 6.0.1 as the receiving node. In order to increase the accuracy, a simple static Kalman filter was also developed. The Kalman filter's main purpose is to correct for noise within the environment, and its implementation accounts for an accuracy increase of over 28% over the raw data. The complete system including the filter was designed to be fully mobile, making the proposed navigation system relatively lightweight and easily upscaled.

II. Indoor Navigation Systems

Indoor navigation has emerged as an interesting field of research, with various solutions being implemented around the world today. There are many methods and research exploration of this topic, each with their respective advantages and drawbacks.

Many indoor navigation systems rely on vision systems and image data to provide the navigation services. These systems can be fairly accurate but are often expensive and complex due to the requirement of extensive environmental data. The research introduced in [12] presents the development of a self-deployable vision-guided navigation system. Although the system requires vast amounts of image information about the environment, leaving it susceptible to error in a dynamic environment where features may change.

In a similar fashion, in [13], image data is utilized to do feature detection as a means of indoor navigation. Other notable visual-based navigation systems make use of Augmented Reality (AR) technology, such as the work presented in [14].

With regards to BLE beacon-based solutions, recent research has emerged in the feasibility of developing indoor navigation systems, of the like seen in [6]. Much of the research builds off each other and attempts to provide some novelty, especially with regards to accuracy, over previous solutions. BLE beacons can be configured to increase their respective transmit powers and transmit intervals for an increase in accuracy improvements, but at the cost of increased power consumption, and so various other techniques are being researched to improve the accuracy without affecting the power efficiency of the BLE beacons. There are still aspects that require additional research but RSSI filtering is a common aspect of a lot of the available research in this field [4]. In [5], various iterations of a particle filter are adapted to BLE beacon RSSI data in order to determine the particle filter's optimal parameters. It was proven that the particle filter was effective in reducing the error compared to the RSSI data in its raw form. Alternate filtering techniques such as Gaussian filters are explored in [7]. It is clear that filtering or smoothing techniques are necessary to overcome environmental noise and improve the performance of beacons.

Aside from the obvious challenges regarding accuracy due to the signal noise present in almost any indoor location, another important consideration is with regards to user acceptance. The BLE beacon approach requires no image data, and so, users may be more inclined to use this system versus a visual-based system that would require them to surrender much more of their privacy. The concerns regarding microlocalization accuracy and user acceptance are explored in [15]. Privacy concerns and other user perspective issues with regards to location services are studied in more detail in [16].

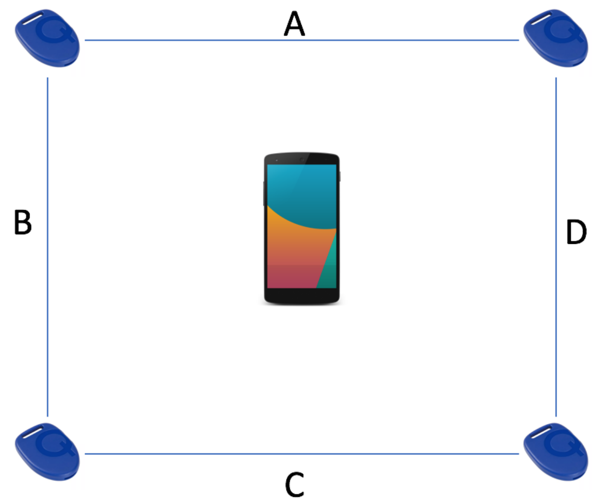

Fig. 1. Experimental setup.

In this paper, we design a simple BLE beacon based indoor positioning model with the addition of a fully implemented static Kalman (KF-ST) filter on an Android application, for accuracy improvements. Three topologies are explored and compared to determine feasibility and verify the filter performance.

III. Methodology and Experiments

To examine the performance of beacons, experiments were conducted. Three different topologies were examined with four beacons and an Android application was developed.

A. Experimental Setup

There is a huge variety of BLE beacon devices on the market. Each has their own unique features, such as additional sensors, power source, reconfigurability, and size. Fundamentally, however, they all work the same. Depending on the application, it may be important to choose more wisely.

In this experiment, four Gimbal Series 21 beacons [17] were used along with a Google Nexus 5 smartphone, running Android version 6.0.1 and having Bluetooth 4.0. Each beacon was configured to transmit every second at a power of 0 dBm. An Android application that utilizes the `AltBeacon` Android library is utilized to interact with the BLE beacons and a measuring tape was used to provide accurate distance placements during the experiments.

The four beacons were placed in three topologies so that they created a square perimeter with the distance to their adjacent neighbours, being 1m, 2m and 6m respectively. The smartphone was placed at four predefined spots, A, B, C and D and communicated with the beacons to find its location. Figure 1 depicts the topology used in this experiment. The test environment was a computer laboratory room of size 7×8 m at the University of Guelph Richards building. There were tables, chairs and computers that filled most of the room.

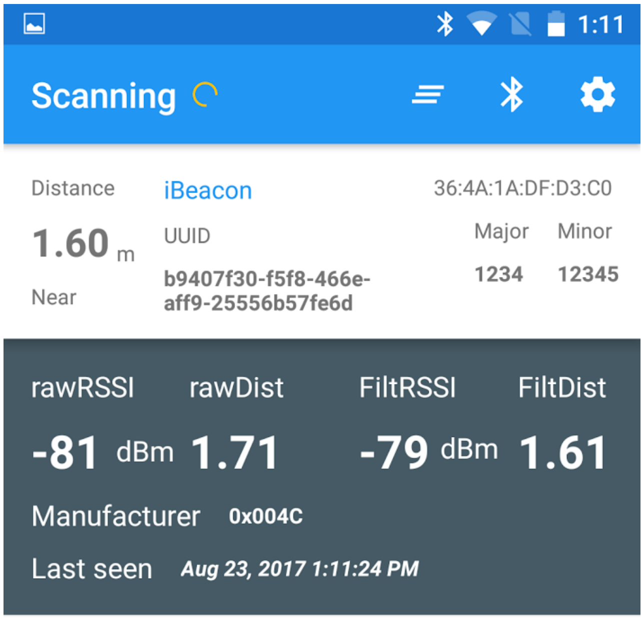

Fig. 2. Android Application: Beacon Scanner - Screen shot.

B. *Kalman filter implementation*

A simple Kalman filter is implemented in the Android application shown in Fig. 2. The filter has two stages; prediction and update. The stages are necessary as the filter makes predictions on the RSSI signal based on the previously determined RSSI value and some environmentally determined gain value. It finally updates the variables before its next iteration. The algorithm is implemented the same as in [8]. The only modification made is to the Kalman tuning parameter for observation noise. This was increased to 20 dBm in order to make up for the added interference the four beacons incurred due to their close proximity to each other, especially in the first two topologies.

IV. Experimental Results and Analysis

The experimental results for position C are shown in Fig. 3, Fig. 4 and Fig. 5 and the absolute average error is shown in Tables I, II, and III.

According to experimental results, in the smallest topology, the accuracy is low, as shown in Fig. 3. Most distance values show to be far outside of the beacon fence boundaries. This is mainly due to the interference created by the four beacons. An interesting insight is that although in previous research it has been reported that beacons accuracy increases when the distance between the beacon and the device is between 1 to three meters [5], this experiment shows that when more beacons are added in the area, the accuracy decreases. This is primarily due to the signal interference each beacon incurs from each other. Extrapolating from these results, it may only be feasible to implement region identification or resource tracking in very small indoor environments using BLE beacons.

In order to mitigate the out of bounds positioning error, we increase the distance between the beacons, hence the three

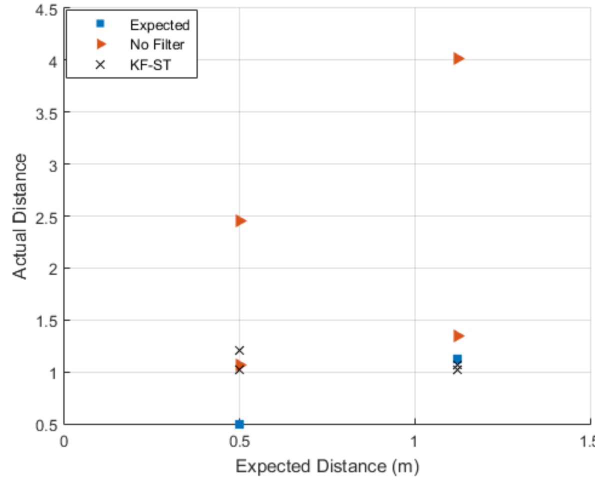

Fig. 3. Topology 1: 1 × 1 m.

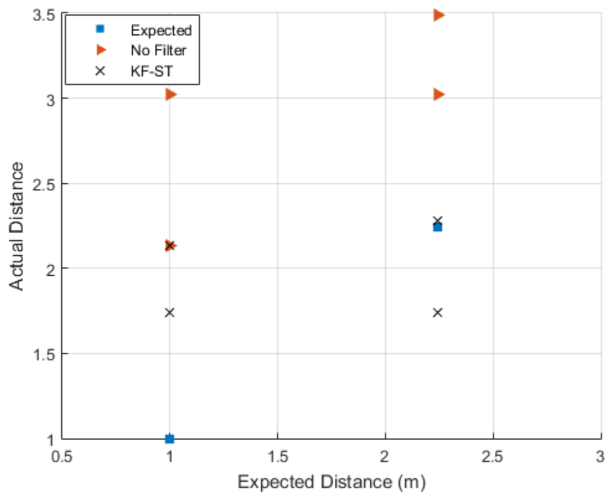

Fig. 4. Topology 2: 2 × 2 m.

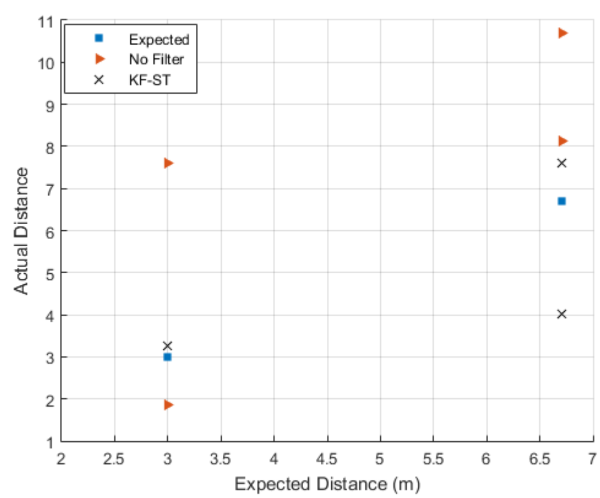

Fig. 5. Topology 3: 6 × 6 m.

TABLE I
1 BY 1 M FENCE - ABSOLUTE AVERAGE ERROR (m)

	Position A	Position B	Position C	Position D	Overall
No Filter	1.58	0.75	1.41	0.60	1.09
Static Kalman	0.19	0.01	0.27	0.31	0.78

TABLE II
2 BY 2 M FENCE - ABSOLUTE AVERAGE ERROR (m)

	Position A	Position B	Position C	Position D	Overall
No Filter	1.33	1.56	1.30	2.44	1.66
Static Kalman	0.37	0.22	0.35	0.45	0.35

TABLE III
6 BY 6 M FENCE - ABSOLUTE AVERAGE ERROR (m)

	Position A	Position B	Position C	Position D	Overall
No Filter	0.66	2.60	2.21	1.88	1.84
Static Kalman	2.09	2.22	0.33	0.18	1.21

topologies. The second topology, shown in Fig. 4, has the lowest average error overall. Filtering brought the distance values close to or within the beacon fence boundaries. This clearly proves that there is a proportional relationship between beacon separation and accuracy. Signal interference between beacons decreases as the distance between the fixed beacon positions increases. This relationship likely has a limit and should be explored in future research. The final topology shows very good results for position C, as seen in Fig. 5. However, the overall average error is worse due to obstacles in the environment. In the 6×6 m topology, unavoidable obstacles such as desks and chairs eliminated the line of sight, hence the poor accuracy. In all experiments, the beacons were placed on the floor. Increasing beacon elevation may have avoided this issue.

It is clear that Kalman filter improves the system performance, as depicted in the overall average error in Tables I - III. The overall error is improved by 28.4%, 78.9%, and 34.2% for the 1m, 2m, and 6m topologies respectively. It is important to notice that the filter is implemented on the developed Android application, hence the results are obtained locally on the device, without the need for server communication. This allows for a light-weight system that is easily adapted and scaled in multiple environments.

V. CONCLUSION

This paper explored the feasibility of BLE beacon navigation systems by implementing a simple four beacon geofencing positioning model. The model explores three separate topologies of various sizes (1×1 m, 2×2 m, and 6×6 m). The indoor positioning model is developed to be fully wireless and integrated with smartphones. In addition, a lightweight, and fully mobile, static Kalman filter was developed to improve the positioning accuracy obtained in the model.

According to experimental results, the size and locality of the geo-fence play a role in the attainable accuracy. The addition of a static Kalman filter can improve the position accuracy up to 78.9% in the tested environment. More specifically, the experiments showed a relationship between signal noise and co-beacon proximity. The closer the beacons are to each other, the greater the effects of signal noise. Hence, this system is best implemented in larger indoor environments.

Future research will look at changing the altitude/elevation of beacon placement and observe the effects it has on the accuracy of the geo-fence model presented in this paper. Alternative filtering algorithms and a variety of other beacon devices should also be tested in an attempt to improve system accuracy and verify its feasibility.

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