Antitheft Technology for Smart Carts Using Dual Beacons and a Weight Sensor

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Recently, various forms of theft and loss prevention technologies have been proposed, including beacons for the prevention of missing children, the theft of strollers, and the loss of passports. However, technologies using only one beacon may send a notification that they have been lost even when they are not outside the range of the beacon signal. In addition, this technology often fails to prevent loss because it only sends an alarm to smart devices after they are a long distance from the owner. Therefore, we propose a technology that uses two beacons to improve antitheft performance. At the same time, we propose an antitheft technology for smart carts using dual beacons and a weight sensor. To verify the performance of the proposed method, we performed a comparative experiment with an existing method using one beacon, and the experimental results showed that the proposed method had 96.5% accuracy. In addition, the antitheft technology using a weight sensor also confirmed that the theft notification was highly accurate. Thus, the proposed technology will be useful for protecting the luggage of those who use airport smart carts and will also be useful for a variety of other purposes, including the prevention of missing children, the theft of strollers, and the loss of passports.

1. Introduction

Recently, with the increasing penetration of smart devices and the development of indoor positioning technology, various information-providing service technologies using the beacon function based on Bluetooth 4.0 have been proposed. Beacon technology, known through Apple’s iBeacon, has the advantage of knowing the location of users more accurately indoor [1] and it is often used as a trigger signal for information delivery because the maximum range reaches 70 m [2]. Thus, using this advantage, 65 Apple iBeacons were installed at two major league baseball stadiums (Dodger Stadium and San Diego Petco Park) in the 2014 season, providing users with services to locate coupons or seats [3]. In South Korea, SK Planet’s Syrup and YAP Company’s YAP have also launched services using beacons that can easily check and provide useful information, such as discounts and coupons, from nearby stores depending on the user’s location [4]. Most universities in South Korea also use beacon-based services as an attendance confirmation system [5]. Concerning indoor positioning technology, users’ real-time movements and user positioning studies using triangulation algorithms are continuously conducted using Estimote Bluetooth Low Energy (BLE) beacons [6], and a system has also been proposed to identify the locations of indoor personnel on naval vessels [7].

In addition to indoor positioning and triggering signals for information provision, the beacon function is also connected to smart devices with various forms of antitheft technologies, such as antimissing bracelets, passport loss prevention technology, and prevention of stroller loss. My Buddy Tag and Lineable, which are serviced as bracelets for preventing missing children, measure the Received Signal Strength Intensity (RSSI) of the beacon to determine the distance between the smart device and the child, thereby representing a technique to prevent missing children [8, 9]. The antimissing bracelets are intended to detect children who are walking away from their parents and prevent them
from doing so, generating notifications if the children are separated from their parents by more than 20 meters. Passport loss prevention technology is a similar technology. When a user places or drops a passport containing a beacon at one location and moves a certain distance away from it, the user’s smart device will be notified [10]. Chung’s proposed stroller loss prevention technology measures RSSI signals to calculate distances, suggesting a technology that stops the stroller’s motor, thinking that a stroller would have been stolen if it moved farther than a certain distance [11].

However, because all of these technologies use only one beacon to provide lost and stolen services, they are often less accurate and more error-prone due to noise from RSSI signals. When using raw data from RSSI signals, many researchers employ Kalman filters to solve the problem of increasing noise generation as beacons and smart devices become separated by greater distances. However, this is also highly influenced by noise, often resulting in theft notification errors even though the distance is not great. Thus, a new method is needed to minimize the influence of noise when a smart device and the beacon are close to each other. Further, with respect to smart carts, there is a need for not only anti-theft notifications about distance but also a way to prevent the stealing of luggage from a cart even if it is at the same distance.

Therefore, in this work, we propose a method for handling distance measurement that is stronger against noise than the existing method by using two beacons rather than one and by applying Kalman filters. Using dual beacons and a weight sensor, we developed smart cart that provides anti-theft capabilities for airport carts. The developed smart cart has a muscle support motor that can assist the user’s pushing force and can force the wheels to stop actively and manually to prevent theft when the distance between the smart device and the cart becomes distant. Smart carts have Bluetooth modules for communication with smart devices and two beacons for generating RSSI signals to prevent theft. Three three-line load cells are installed together to measure the weight change in the smart cart. Currently, the distance is measured according to the receiving strength of the RSSI signal on the two beacons and is divided into Immediate, Nearness, and Farness for use as a distance measurement value to prevent theft [12]. We use Kalman filters to minimize noise and increase measurement accuracy. Furthermore, we propose an anti-theft algorithm to eliminate these errors, as there is a possibility of a single short distance value due to noise generation.

At the same time, we secondarily propose a technology that can measure the weight of the luggage in the cart and prevent theft by informing the user if there is a significant unintended weight change. We developed a smart cart and an application for smart devices to verify the performance of the proposed distance measurement algorithm and anti-theft technology. We also conducted distance measurement experiments and anti-theft locking experiments using the algorithm and technology. We found from the experimental results that the proposed method showed better performance for RSSI signal noise than using a single beacon by applying a Kalman filter, and we confirmed in the anti-theft locking experiments that the proposed method generates 96.5% accuracy. The method is therefore superior to existing technologies as it is stronger against RSSI signal noise and has a better anti-theft lock success rate. This makes it useful for preventing theft and protecting, for example, a user’s luggage while they shop in an airport by mounting two beacons and a weight sensor to a smart cart. With the dual beacons, it can prevent theft and loss in a variety of other contexts as well; for example, it can be used to locate missing bicycles and children.

This paper is organized as follows. “Previous Work” section describes the RSSI signals of beacons, how to calculate distance values for the signals, and Kalman filters for noise rejection and also describes existing studies using these features. “Anti-theft Technology for Smart Carts Using Dual Beacons and a Weight Sensor” section introduces smart carts with dual beacons and a weight sensor and describes an application for smart devices that performs anti-theft notifications. The section also describes the flow of the service system concerning anti-theft technology. “Experiments and Evaluations” section describes comparative experiments with only one beacon and dual beacons to verify the anti-theft performance of smart carts and additionally discusses anti-theft locking experiments due to weight changes, with the results analyzed thereafter. “Conclusions and Future Research” section presents the conclusions and establishes future research directions.

2. Previous Work

In this section, we describe the RSSI signals of beacons based on Bluetooth 4.0 and the calculation method of distance values from RSSI signals, as well as Kalman filters for denoising. The section also introduces children’s location tracking, antimissing child research, and object loss prevention indoor using beacons. Bluetooth 4.0 is the addition of low energy technology in 2010 by absorbing WiBee technology, an ultra-low-power application technology, into Bluetooth standards. Bluetooth 4.0’s BLE technology is a wireless communication technology that increases the efficiency of power consumption and user accessibility and is most suitable for services that locate and provide information to users. Also, since the power consumption of this technology is 1.5 to 2 mW, it can be used as a coin-shaped ultra-small battery for many years, and it has the advantage of being useable regardless of the OS installed on smart devices, such as Android and iOS.

Using Bluetooth 4.0, the beacon continuously generates RSSI signals to pass on specific ID values to the smart device. At present, we can determine that the larger the RSSI signal value, the closer the distance between the smart device and the beacon. The method of measuring distances using RSSI signal values is shown in the following equations [13]:

\[
\text{RSSI} = -10 \log (d) + Tx\text{Power},
\]

\[
d = 10^{\frac{(Tx\text{Power} - \text{RSSI})}{10\alpha n}}.
\]
Equation (1) describes how a beacon transmits a Bluetooth signal to its surrounding location via the transmission power (Tx power) and shows how a smart device located within the beacon signal range determines the power of RSSI signals from the beacon. By transforming equation (1), the distance between the beacon and the smart device can be calculated, as shown in equation (2). The dBm value, a unit of RSSI, is a unit of power in mW on a dB scale. As this value approaches zero, the distance from the beacon is closer, and, as the negative value increases, the distance from the beacon is greater. However, the farther away the RSSI signal in the beacon, the noisier it becomes, and its value is often inconsistent. In Wouter’s experiments, there was a difference of approximately 9 dBm of noise in the range of 30 cm to 60 cm, 28 dBm of noise in the range of 1 m, and 11 dBm of noise in the range of 3 m [14]. As a way to address this noise, Wouter introduced a way to apply the Kalman filter and provided the experiments and results regarding this application, as shown in the following equation [15]:

$$\text{RSSI}_{\text{smooth}} = \alpha \times \text{RSSI}_n + (1 - \alpha) \times \text{RSSI}_{n-1}. \tag{3}$$

In equation (3), \(\text{RSSI}_{\text{smooth}}\) is the most recent RSSI value, \(\text{RSSI}_{\text{avg}}\) is the average RSSI value from the previous RSSI, and \(\alpha\) is the variable value of 0.75 from 0 to 1. Thus, Wouter was able to reduce noise to within 3 dBm at a distance of 1 m by applying the Kalman filter, as shown in Figure 1.

Figure 1 shows that the RSSI raw value is at least −86 dBm, up to −58 dBm, and the noise generated by the 29th and 30th positions is −86 dBm. The RSSI value with the Kalman filter is also rarely affected by the noise.

Next, Back recently studied an infant positioning real-time notification service and a children’s indoor positioning service using beacons [16]. In this study, children’s devices were used in a Broadcast mode, with beacons transmitted to the surrounding area. Teachers can thus use smart devices to identify the children's current locations. The beacons produced for the experiment showed a low error range of about 0.5 m and high accuracy within a close range of 30 m. In a similar way, Taileb proposed indoor and outdoor child-tracking systems using GPS and Bluetooth together [17]. If a smart device finds a surrounding beacon signal, it can be determined that the child is in range; if the signal is not found, the location of the child can be found on a map using GPS/GSM (Global System for Mobile Communications). Jang proposed a loss prevention and recovery system that measures the distance between beacons and smart devices possessed by children, elderly people with dementia, and disabled people and notifies users with warning information if they exceed a certain distance [18].

3. Antitheft Technology for Smart Carts Using Dual Beacons and a Weight Sensor

In this section, we introduce the flow of service systems to prevent theft between smart carts and smart devices with dual beacons and a weight sensor and describe a proposed application that gives antitheft notifications. The overall flow of the proposed system is shown in Figure 2.

In Figure 2, it can be seen that motor driver and control hardware use the BLDC motor driver and RS485, and, for communication, Bluetooth uses HM-10 (Connection Mode). Two beacons, used for antitheft distance measurements, employ the Basbea i4 model (Broadcast mode): the first beacon with a specific name and the second beacon with "_" added after that name. To measure the weight change via a Wheatstone Bridge circuit, a weight sensor uses three three-line load cells.

Users can deploy the proposed application to search for smart carts to connect to their surroundings and can complete pairing by entering the specified password. After that, a search for a beacon in Broadcast mode can be performed to prevent theft by distance (①) and the smart cart can be connected to the beacon (②). Smart devices continuously receive RSSI signals from beacons in smart carts and calculate distance values (②). If the beacon moves farther than a certain distance, the proposed application notifies the user of the theft of the smart cart (④). At the same time, the smart device sends commands to stop the motor in the smart cart (⑤), and the smart cart, which is commanded by the motor driver, stops the wheels from moving (⑥). In addition, the smart cart continuously measures the weight of the currently loaded luggage through Bluetooth communication and sends this information to the smart device to determine whether the weight changes are within the range set by the user (⑦). If someone picks up their luggage and the weight changes significantly (⑧), a notification about the theft of the smart cart is sent to the user and the same antitheft procedure is conducted (③, ⑤).

The connection between the application on smart devices and data communication with smart carts is depicted in Figure 3. In this figure, the user touches the "Connect Smart cart" button (left side of Figure 3), selects the name of the cart to connect when the middle list appears, enters the password on (right side of Figure 3), and completes the connection.

When the application is connected to the smart cart, it moves on to the next screen, as shown in Figure 4. The application displays the connected cart name as shown in the upper left corner of Figure 4 and, next to it, provides the “Disconnect” button to disconnect.

In Figure 4, the user selects the cart by touching the “Add Smart cart” button to set the antitheft settings according to the distance (①), and the application then displays the selected cart name in the middle of the screen, as shown on the right side of Figure 4 (②). At the same time, the “Unlock Smart cart” button is activated as the “Lock Smart cart” button to allow the user to manually stop the cart. The lower screen of the application can be configured as shown in Figure 5, and the antitheft algorithm according to distance can be set as follows.

The application continuously collects RSSI signals from dual beacons on the smart cart and applies a Kalman filter to calculate current RSSI values and iterate the antitheft algorithm. The RSSI value is calculated as the distance value; if the distance value exceeds the threshold value, the smart cart is determined to be away from the user and the countAlarm value for the alarm is increased. As the proposed method
uses dual beacons, the application prioritizes the RSSI signal value of the beacon in Figure 2 (②). If the RSSI value of that beacon is lower than that of the second beacon, the application makes a calculation by changing the RSSI value of the secondary beacon to a distance value. If the countAlarm value exceeds the thresholdCount specified during repetition, the algorithm executes the LockSmart() function to notify the user of the theft of the smart cart via local notification and automatically sends a command to the smart cart to stop the motor. The automatic antitheft algorithm

Figure 1: The effect of a Kalman filter on raw RSSI data sampled from a static device.

Figure 2: The flow of antitheft technology for smart carts using dual beacons and a weight sensor.
according to the RSSI signal distance in Figure 5 can be represented in pseudocode, as shown in Figure 6.

In Figure 6, the proposed application initializes the countAlarm value at 0 when the connection with the smart cart begins, and it sets the thresholdValue value to $k$. The application collects RSSI values for antitheft measurements, applies Kalman filters, calculates distance measurements divided by five levels (Immediate: 1, I–N: 2, Near: 3, N–F: 4, Far: 5) as a division() function, and displays distance values on the application screen as showDistance(). If the smart cart is in Near, the countAlarm value is entered as 0. If the smart cart is located farther away (over N–F), the countAlarm value will increase. If the countAlarm value exceeds the set threshold value, the user is notified by a theft alarm as the PreventionAlarm() function, and the LockSmart() function stops the motor of the smart cart. The antitheft notification algorithm according to weight change is shown in Figure 7.

On the application screen in Figure 7, when a user enters a protective weight for an antitheft alarm and touches the “Set” button, which is shown in the bottom right of the figure, the application executes the algorithm according to the weight change. $W_{n-1}$ is the previously measured weight, and $W_n$ is the current weight. If the difference in weight is greater than or equal to the user’s set value (Protect weight), the application determines that there has been a significant change in weight and executes the LockSmart() function. The LockSmartCart() function shows users a theft
notification due to a weight change of the smart cart via a local notification, which automatically gives a command to the smart cart to stop the motor, thereby stopping the smart cart from moving.

4. Experiments and Evaluations

In this section, we explain comparative experiments and their results on distance measurements using only one beacon, a Kalman filter, and the proposed method to verify its antitheft performance. We also explain antitheft locking experiments and their results using a distance algorithm and a weight change algorithm for antitheft notification.

The connection mode Bluetooth used in the experiment was HM-10, the BroadCast mode beacons used two Basbea i4, the microprocessor of the smart cart was STM32F765, and the smart device was an iPhone 11 pro. Distance measurements for the beacons and the smart cart were collected 40 times per distance, with a total of three values: raw data from one beacon, Kalman filter data from one beacon, and Kalman filter data from two beacons. The Tx power value for the beacon was set to −59 dBm, transmission power 7, and broadcasting interval 200 ms. Figure 8 depicts the result of collected RSSI data when the distance between the beacon and the smart device was 30 cm and 60 cm. In Figures 8(a) and 8(b), we can see that the data from one...
beacon and two beacons with the Kalman filter match perfectly. This is because the distance is so close that there is no significant noise, so one beacon value was applied equally. The values 5, 3.8, and 3.8 on the right side of the graph represent the difference between the highest and lowest values of each data type, with 5 dBm being the raw data, 8 dBm being the Kalman filter data, and 3.8 dBm being the dual beacon data. The difference in raw data was greater than that of the other two data types due to some of the effects of noise.

Figure 9 shows the data measurement results at a distance of 1 m. In the figure, we can see a change in the RSSI raw data (difference value: 16 dBm) by a large margin compared to the 30 cm and 60 cm positions, whereas the Kalman filter and the dual beacon values are similar (difference value: 12.1 dBm).

Figure 10 depicts the results of measuring RSSI data at distances of 3 m, 6 m, and 10 m. In the figure, the Kalman filter values using one beacon at 3 m show a difference of 7.51 dBm from −66.22 dBm to −73.73 dBm, while the proposed method shows a difference of 6.75 dBm from −65.81 dBm to −72.56 dBm. At 6 m, the Kalman filter shows a difference of 8.24 dBm from −74.02 dBm to −82.27 dBm, while the proposed method shows a difference of 6.76 dBm from −73.76 dBm to −80.52 dBm. At 10 m, the Kalman filter ranged from −83.5 dBm to −95.52 dBm, with a 12.03 dBm difference, and the proposed method had from −82.09 dBm to −89.57 dBm, with a 7.48 dBm difference.

In other words, we can see that the farther the distance is when only one beacon is used, the weaker the RSSI signal strength and the greater the deviation of noise even when the Kalman filter is applied. However, the proposed method can confirm that the noise deviation is not significant for the RSSI signal compared to the single beacon, even if the distance is greater.

Next, we conducted an antitheft notification experiment according to distance using a smart cart with dual beacons installed and via the proposed application. The five levels of distance measurement set by the application are shown in Table 1.

The application sets the levels and values in Table 1 according to the RSSI value received and displays the icon image in five steps next to the “Smart cart” text shown in Figure 5. If the receiving level is Near-Far and Far, the countAlarm is increased in the pseudocode (shown in Figure 6), and the thresholdValue is set to 5 so that the antitheft alarm can be activated. The antitheft experiment placed smart carts and smart devices within Near range for a period of time and verified that antitheft notifications worked well. The smart device and the smart cart were placed in 1 m to 7 m positions for 10 minutes each, and we identified how many antitheft notifications occurred using a single beacon and the proposed dual beacons. Figure 11 depicts the results of the experiment.

As shown in Figure 11, antitheft notifications using one beacon occurred six times at 4 m, nine times at 5 m, 12 times...
at 6 m, and 28 times at 7 m. Thus, the notifications occurred a total of 55 times within a range of 7 m in 70 minutes. On the other hand, the proposed method, dual beacons, sent antitheft notifications twice at 6 m and three times at 7 m, for a total of five times in the same period of time. We can see that the antitheft alarm was not activated within 5 m. Yet, at distances closer to 7 m (Near-Far), set by the antitheft algorithm, the antitheft alarm was activated. Next, we performed an experiment using dual beacons to generate antitheft notifications for 10 to 60 minutes at each distance. Figure 12 shows the result of the experiment.

As shown in Figure 12, only one antitheft notification occurred at 60 minutes within 5 m, whereas it occurred eight times at 6 m and 12 times at 7 m. In other words, the occasional occurrence of antitheft notifications at a position of 6 to 7 m as the smart cart moved away from the smart device can be expected due to the noise generated by the beacon reaching the value set by the proposed algorithm. Next, we
conducted an experiment on whether antitheft notifications worked well at distances over 7 m. We moved the smart cart, which was located within 5 m, to a position of 8 m, 9 m, and 10 m in 5 seconds, and we checked that the antitheft notification worked within 10 seconds. The reason for checking this was that the receiving cycle of the smart device’s beacon data is 1 second, and the thresholdValue is set to 5 seconds, i.e., twice the time of 10 seconds.

To compare performance, we experimented with the use of one beacon and the proposed method, and the number of measurements was 100 times for each location. Figure 13 depicts the results of the antitheft notification experiment according to distance.

As shown in Figure 13, when using one beacon, the application sent an antitheft notification approximately 87.75% of the time, for a total of 351 times: 78 times, 85 times, 93 times, and 95 times at each location. On the other hand, the proposed method sent an antitheft notification a total of 386 times: 91 times, 95 times, and 100 times at each location, indicating 96.5% accuracy. The reason for the low accuracy when using a single beacon is likely that due to RSSI signal noise; the thresholdValue is often initialized at 0 before it reaches 5 or higher. The proposed method also confirmed that nine and five antitheft notifications were not issued within 10 seconds at the 8 m and 9 m positions, respectively, but all notifications occurred after 10 seconds.

Next, the antitheft notification experiment on weight change used five 5-kilogram bags of rice within 5 m. Initially, all five bags were placed in the smart cart, which consequently weighed 25 kg, and the values set for the weight change were 4 kg and 8 kg. In total, 100, 200, and 300 experiments were conducted, losing 5 kg and 10 kg at a time to yield a weight change and checking antitheft notifications. Figure 14 shows the results of an antitheft notification experiment by weight change.

As shown in Figure 14, for the first 100 experiments, weights of both 4 kg and 8 kg triggered a theft notification due to the weight change 100% of the time. For the next 200 experiments, one theft notification did not occur at 4 kg; for the last 300 experiments, one theft notification did not occur at 4 kg, and two theft notifications did not occur at 8 kg. Thus, we confirmed that the success rate of theft notifications was over 99% in the weight change experiments. The reason why theft notifications did not occur in the 200 and 300 experiments was that the initial weight was not set to 25 kg because one bag was not placed correctly, causing the measuring sensor to malfunction or load with all 25 kg.
In conclusion, based on the results of the antitheft experiments on distance and weight changes, the smart cart and the smart device application proposed in this paper represent useful technology for the prevention of theft and the protection of the user’s luggage when shopping in airports.

5. Conclusions and Future Research

In this paper, we proposed a theft prevention algorithm for smart carts based on distance changes using two beacons with Kalman filters rather than one beacon. We also proposed an algorithm that can generate an antitheft notification if the weight changes significantly using a weight sensor. We confirmed that RSSI signal collection using dual beacons and an antitheft notification algorithm according to distance change showed superior performance in comparative experiments with the existing method. The experiment also confirmed that antitheft notifications due to weight changes showed high accuracy. Thus, the smart cart and smart device application proposed in this paper is a useful service technology that can help airport passengers safely protect their luggage, and it shows promise as a foundation for commercial technologies in many airports around the world. Furthermore, because the proposed algorithm uses a dual beacon method, it performs excellently with respect to antitheft notifications. It is therefore also useful as an antitheft measure for smart strollers, smart bicycles, and baggage.

The proposed work has two main limitations. First, there is noise even when the dual beacon method is used, and the difference of RSSI values between the two beacons is significant sometimes. Second, the experiment found a high antitheft notification error rate in the 6–7 m section; we do not know what the impacts of this are.

Therefore, we will study noise reduction methods utilizing the RSSI average signal strength of two beacons in addition to a Kalman filter, and we will determine how to reduce the rate of antitheft notification errors that occur between 6 and 7 m. We will also examine a new algorithm that can reduce the increase in RSSI intervals due to noise as the distance increases from 6 m to 10 m. In addition to the RSSI signals from beacons and antitheft notifications due to weight change, the types of theft that can occur when using smart carts will be explored, and we will research techniques and technologies to prevent the theft of luggage placed in smart carts.

Data Availability

No data were used to support this study.
Conflicts of Interest

The author declares that there are no conflicts of interest.

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References


