Cooperative Line Wait Time Estimation Using BLE on Smartphone

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Abstract  People often have to stand waiting in a queue, which they may find disagreeable. Facilities where people must wait, for example, food courts, banks and amusement parks, need to recognize and provide an estimated wait time to increase customer satisfaction. Hence, there is demand for wait time estimation methods. Also, the requirement for estimation accuracy changes with the length of the queue. In this paper, we propose a cooperative line wait time estimation method using Bluetooth low energy (BLE, marketed as Bluetooth Smart) on a smartphone. To estimate the wait time, we utilize the stay-times of users approaching and moving past two preinstalled receivers. The wait time is estimated by the difference between the two stay-times. Our stay-time estimation includes two methods: a direct-wave blocking method and a stay-time estimation method. We experimentally evaluated with our method in a passageway of our university campus for different values of the range value which is a parameter used in the stay-time estimation. It was found that when the range value was set to 4-8 dB, almost all of the devices estimated the wait time to be within 20 s of from the expected wait time. This result satisfied the requirement of all users according to our questionnaire about discontent with erroneously estimated wait times.

Keywords: human line, wait time, Bluetooth low energy, RSSI, smartphone

1. Introduction

When people are queueing, for example, at food courts, banks, and amusement parks, an unclear and long wait time may be disagreeable. In [1], Houston et al. proposed that there is the close relationship between a wait time and the user’s evaluation of service quality. To solve this problem, facilities have focused on estimating and displaying the wait time during busy times. In general, the wait time is estimated by counting the number of people waiting in a line or by using an estimation method requiring the installation of costly special devices, such as monitoring cameras or infrared sensors. Nowadays, there is demand for low-cost wait time estimation methods that do not rely on costly special devices.

Also, smartphones equipped with a Bluetooth low energy (BLE) device are now commonly used. BLE is a part of the Bluetooth 4.0 standard and it operates with very little power [2]; the transmitter can be driven with a coin battery or a button cell battery. Broadcasting radio waves in the 2.4 GHz frequency band is possible in N-to-1 short-distance wireless communication and does not need connection or authentication. iBeacon is Apple’s application using BLE broadcasting and it uses the advertisement packet specified in Bluetooth 4.0 [3, 4]. Eddystone developed by Google also uses BLE broadcasting [5].

Smartphones provide various services by receiving BLE waves including iBeacon. Such devices are sometimes applied to understand human behavior.

In this paper, we propose a new estimation method for the wait time in a human line by analyzing BLE waves transmitted from a smartphone application. This paper is an extended version of [6].

The rest of the paper is organized as follows. Section 2 reviews related works. Section 3 describes our two proposed methods. Section 4 describes our experiments and results. Conclusions are presented in Sect. 5.

2. Related Works

There have been many studies on travel time estimation such as in human lines or on the road.
In [7], Hu et al. described SmartRoad, a road-sensing system. This system estimated the travel time on the road using the Global Positioning System (GPS), a motion sensor, vehicle internal sensors and Wi-Fi communication. Also in Japan, a travel time measurement system (T-system) is utilized to crack down on speeding offenses by the image recognition of car license plates [8]. At the same time, the T-system estimates the congestion level on the road, then the travel time is estimated from the congestion level. These systems are focused on the road, not human lines. In [9], Bulut et al. described the design, implementation and deployment of LineKing (LK), a crowdsourced line wait time monitoring service, at a coffee shop. This design requires smartphones to transmit acquired information to a cloud server. In our proposed method, we utilize BLE waves broadcast by smartphones. Therefore we do not require connection or authentication or data communication between smartphones and a server. In [10], Yamamoto et al. described a position estimation method in a line of people using Bluetooth communication. Using the Received Signal Strength Indicator (RSSI), which measured the Bluetooth communication between nearby devices, they estimated the relative positions where the users were standing. Although this paper focused on position estimation in a human line, it did not propose a wait time estimation method, which is our aim.

3. Proposed Method

In our study, users are walking past two receivers. We show the measurement environment in Fig. 1. We install one receiver at Point A, where we measure the wait time until a person arrives at the head of a line, and the other receiver at Point B at the head of a line. Smartphones as peripheral devices broadcast BLE advertisement packets, and the receivers as central devices receive them. We estimate the wait time by analyzing the RSSI values at the two receivers. To estimate the wait time, we utilize the stay-time between the users approaching and moving past each receiver. The stay-time is determined by two factors: whether or not the user is beside the receiver and the time during which the user is beside it. It is necessary to detect these factors only from the RSSI value. Hence, we propose two methods for detection: a direct-wave blocking method and a stay-time estimation method.

3.1 Direct-wave blocking method

To recognize whether or not a user is beside the receiver, it is useful to use the maximum RSSI value. The RSSI value is related to the distance: the shorter the distance between the user and the receiver, the higher the RSSI value is received. The maximum RSSI value may be obtained from direct waves. The problem is that even if the user is not beside the receiver, the receiver may receive direct waves from the user. Physical objects and human bodies can block signal waves and reduce the RSSI [3]. Hence, we propose installation of a stainless-steel barrier wall in each receiver to block direct waves. The barrier wall blocks direct waves while the user is behind the receiver, and the user’s body blocks them while the user is in front of it. We show the direct-wave blocking environment in Fig. 2. In order to confirm the effectiveness of the barrier wall, we conducted a preliminary experiment.

3.2 Stay-time estimation method

The fluctuation of the RSSI while the user is standing is less than that while the user is walking. If the line is crowded and the users are standing for a long time beside the receiver, it is impossible to estimate the stay-time using only the maximum RSSI value. To estimate the stay-time when the user is standing beside the receiver, we propose the use of data sets consisting of the observed data between a slightly lower value than the maximum RSSI value and the maximum RSSI value. We define this slightly lower value as the range value and select the range value from a certain range. The range of the range value is discussed in Sect. 4.3.2.

We define time stamps $t_{in}$ and $t_{out}$ for the earliest received time and the latest received time, respectively, in the data sets. The stay-time is the difference $t_{out} - t_{in}$.

We estimate these two time stamps for each receiver. In other words, we estimate time stamps $t_{A,in}$, $t_{A,out}$, $t_{B,in}$ and $t_{B,out}$ when the user enters and leaves Points A and B, respectively, as shown in Fig. 3. The user leaving Point B corresponds to finishing waiting in line. We show an example of the measured RSSI while the user walks past two receivers in Fig. 3.
The solid line and dashed line respectively show the measured RSSI fluctuations at Points A and B. Having these time stamps, the estimated wait time is the difference $t_{B\text{-out}} - t_{A\text{-in}}$.

4 Experiments and Results

We used the iOS devices of the people cooperating in the experiment as BLE wave transmitters (iPod touch (6th generation), iPhone 5S and 6). These devices broadcast iBeacon as BLE waves from iOS applications [11]. In addition, the Wi-Fi was turned off in these devices because BLE and Wi-Fi use the same 2.4 GHz frequency band.

Advertisement packets always have the same length and are composed of a series of fixed fields [3, 4]. We show the structure of iBeacon advertisement packet in Fig. 4. The advertisement interval is preset in the iOS application and we cannot change it. We set various values on Minor, where Minor is a unique ID to distinguish cooperating users.

We used two Raspberry Pi devices (model B+) equipped with a BLE dongle as the BLE wave receivers. The two receivers and a laptop PC were connected so that their times were synchronized. The receivers did not record the observed data when receiving BLE waves whose UUID and Major values were different from those in our setting. The recoded items in the receivers consisted of the Minor, the RSSI and the received time.

4.1 Experimental environment

All experiments were conducted in a passageway of our university campus. We show the experimental environment in Fig. 5. Experiments were conducted with a 7 m line with eight standing points. The 2 m and 7 m points corresponded to Points A and B, respectively. At these points, a stand with a mounted receiver was placed.

4.2 Preliminary experiment

One cooperating user was asked to hold a smartphone at each of the eight standing points in experiments without and with the barrier-wall. Figure 6 shows the preliminary experimental environment. In this experiment, there was only one user holding a smartphone in the line. This experiment used three devices: iPod touch, iPhone 5S and iPhone 6. We show the design of the receiver with the barrier wall in Fig. 7. All barrier walls were set in the direction in which the user walked, as shown in Fig. 5. The user stood waiting for 1 min at each standing point.
We show the observed maximum RSSI value at Point A without and with the barrier wall in Fig. 8 and Fig. 9, respectively. When the experiment was conducted with the barrier wall, the observed maximum RSSI value at Point A was higher than that at the other points. This result indicates whether or not the user is beside the receiver. Therefore, the effectiveness of the barrier-wall is proven.

4.3 Evaluation experiment

Under the same circumstance as in the preliminary experiment, eight cooperating users were asked to hold a device in their hands. Figure 10 shows the environment of the evaluation experiment. All users moved forward one position every minute, then waited for 1 min.

![Fig. 8 Preliminary experimental result without barrier wall at Point A](image1)

![Fig. 9 Preliminary experimental result with barrier wall at Point A](image2)

Therefore, the expected wait time was 6 min (360 s). This experiment used eight devices: three iPod touch devices, three iPhone 5S devices and two iPhone 6 devices.

For each device, the BLE was turned on when the user reached the starting point (0 m) and turned off when the user left Point B. We performed two measurements for each device with two minor values, giving a total of 16 measurements.

### 4.3.1 Questionnaire result for user’s requirement

The users’ requirements for the estimation accuracy of the wait time depend on the length of the line. To evaluate the result of this experiment, it is necessary to listen to their requirements for this experiment. Therefore, we distributed a questionnaire on discontent with the error of the estimated wait time to 12 users. If the estimated wait time was excessively shorter or longer than the expected wait time (360 s), it was assumed that the users would not be satisfied with the estimation result.

With this consideration, we made a survey of the error for which the users felt discontented. We show the result of the questionnaire in Table 1. It was found that none of the users would feel discontented if the estimated wait time error was within 40 s.

### 4.3.2 Experimental results

We show the result of the evaluation experiment in Table 2, which shows the relationship between the estimated wait time and the range value. When the range value was set to a lower value (1-3 dB), some devices estimated the wait time to be shorter than the expected wait time.
Table 2 Estimated wait time for each Range value

| Range Value (dB) | 0-300 | 301-320 | 321-340 | 341-360 | 361-380 | 381-400 | 401-420 | 421-1 |
|------------------|-------|---------|---------|---------|---------|---------|---------|-------|
| 1                | 3     | 3       | 4       | 6       | 0       | 0       | 0       | 0     |
| 2                | 1     | 2       | 3       | 10      | 0       | 0       | 0       | 0     |
| 3                | 0     | 1       | 4       | 11      | 0       | 0       | 0       | 0     |
| 4                | 0     | 0       | 1       | 15      | 0       | 0       | 0       | 0     |
| 5                | 0     | 0       | 0       | 15      | 0       | 0       | 0       | 0     |
| 6                | 0     | 0       | 0       | 15      | 0       | 0       | 1       | 0     |
| 7                | 0     | 0       | 0       | 15      | 0       | 0       | 1       | 0     |
| 8                | 0     | 0       | 0       | 15      | 0       | 0       | 1       | 0     |
| 9                | 0     | 0       | 0       | 13      | 0       | 2       | 1       | 0     |
| 10               | 0     | 0       | 0       | 10      | 0       | 5       | 1       | 0     |
| 11               | 0     | 0       | 0       | 8       | 1       | 5       | 2       | 0     |
| 12               | 0     | 0       | 0       | 8       | 0       | 3       | 5       | 0     |
| 13               | 0     | 0       | 0       | 5       | 0       | 4       | 7       | 0     |
| 14               | 0     | 0       | 0       | 4       | 0       | 1       | 10      | 1     |
| 15               | 0     | 0       | 0       | 3       | 0       | 0       | 11      | 2     |

Table 3 Estimated wait time and MAE for each device (First experiment)

| Device Number | Range Value (dB) | MAE |
|---------------|------------------|-----|
|               | 4    | 5    | 6    | 7    | 8    |     |
| 1             | 352  | 354  | 354  | 355  | 356  | 3.6 |
| 2             | 354  | 355  | 355  | 355  | 355  | 3.3 |
| 3             | 357  | 357  | 357  | 357  | 357  | 1.9 |
| 4             | 353  | 353  | 357  | 357  | 357  | 2.9 |
| 5             | 355  | 355  | 355  | 355  | 355  | 3.1 |
| 6             | 328  | 410  | 411  | 411  | 415  | 29.9|
| 7             | 347  | 356  | 356  | 356  | 356  | 3.6 |
| 8             | 354  | 355  | 355  | 355  | 356  | 3.1 |

Table 4 Estimated wait time and MAE for each device (Second experiment)

| Device Number | Range Value (dB) | MAE |
|---------------|------------------|-----|
|               | 4    | 5    | 6    | 7    | 8    |     |
| 1             | 353  | 353  | 353  | 353  | 353  | 4.4 |
| 2             | 350  | 352  | 352  | 352  | 353  | 5.1 |
| 3             | 353  | 355  | 355  | 355  | 355  | 3.4 |
| 4             | 353  | 353  | 354  | 354  | 354  | 4.0 |
| 5             | 349  | 349  | 350  | 350  | 350  | 6.5 |
| 6             | 352  | 352  | 352  | 352  | 353  | 4.9 |
| 7             | 347  | 349  | 350  | 352  | 352  | 6.3 |
| 8             | 349  | 350  | 350  | 350  | 350  | 6.4 |

In such a case, the extraction of data cannot be executed well. That means that the data at the 1 m point and point A may not be distinguished.

When the range value was from 4 to 8 dB, the difference between the estimated and expected wait times were within 20 s for 15 of the 16 devices. Our method can estimate the wait time with higher accuracy if the range value is set within this range. The result for the remaining device may have been an outlier. To analyze the outlier, we calculated the mean absolute error (MAE) relative to the expected time for each device when the range value is from 4 to 8 dB. The MAE used in the analysis is expressed as

$$MAE = \frac{1}{N} \sum_{i=1}^{N} |y_i - y|$$

where $N$ is the width of the range of the range value, $y_i$ is the estimated wait time and $y$ is the expected wait time.

A smaller MAE means that the estimated wait time is closer to the expected wait time. Using a boxplot [12], we detected the outlier. Tables 3 and 4 show the estimated wait time and MAE of each device in the first and second experiments, respectively. In these tables, device numbers 1-3 are iPod touch, device numbers 4-6 are iPhone 5S and device numbers 7-8 are iPhone 6. The parameters for the boxplot are shown as follows, and the closed interval between the lower and upper whiskers of the boxplot is expressed by Eq. (2). $Q_{1/4}$ is the lower quartile, $Q_{3/4}$ is the upper quartile, $IQR$ is the interquartile range ($Q_{3/4} - Q_{1/4}$) and $w$ is the whisker length.

$$[Q_{1/4} - w \cdot IQR, Q_{3/4} + w \cdot IQR]$$
This closed interval includes 99.3% of the data if the data follows a Gaussian distribution in the case of $w = 1.5$. The outlier of the MAE in this paper are the data that appear above the upper whisker. Therefore, the closed interval of the boxplot in this paper is defined by the following equation.

$$[0, Q_{3/4} + 1.5IQR]$$  \hspace{1cm} (3)

The boxplot for the experimental results is shown in Fig. 11. As shown in this figure, only one data was an outlier in the first experiment. This is the data of device number 6 shown in Table 3. Furthermore, this device was not used in the preliminary experiment discussed in Sect. 4.2. To analyze the outlier further, we focus on the measured RSSI in the case of the minimum MAE (device number 3 in the first experiment) and the maximum MAE (device number 6 in the first experiment). The RSSI value is the average of the values obtained every one second. The measured RSSI values of each case are shown in Fig. 12 and Fig. 13.

For device number 3, the RSSI around 120-180 sec and 420-480 sec (at Points A and B, respectively) is significantly higher than that at the other points. However, for device number 6, a high RSSI was obtained at points excluding Points A and B. We think that this problem originated from the dependence on the device type. To confirm that, we focus on the measured RSSI in the case of device numbers 5 and 6 in the second experiment as shown in Fig. 14 and Fig. 15, respectively (Note: device numbers 5 and 6 are both iPhone 5S).

The reason why we focused on device numbers 5 and 6 in the second experiment is that the MAE was higher than that in the other cases. In Fig. 14, the RSSI around 120-180 sec and 420-480 sec (at Points A and B, respectively) is higher than at the other points. However, in Fig. 15, a high RSSI is obtained at points excluding Points A and B. Similarly to in Fig. 13, even when the user stopped at Point A or B, the RSSI fluctuation was large. Although the MAE of device number 6 in the second experiment was small, the cause of the outlier depends on the device rather than the device type. Even if an outlier is occurs, there is no problem because the outlier is deleted.
Therefore, when the range value was set to 4 to 8 dB, almost all the devices estimated the wait time to be within 20 seconds from the expected wait time. In this case, considering the result of the questionnaire shown in Table 1, it is possible to obtain the estimation accuracy required by users.

5 conclusion

In this paper, we proposed a cooperative line wait time estimation method using BLE on a smartphone. First, we proposed a direct-wave blocking method, where the effectiveness of a barrier wall was proven by a preliminary experiment. Second, we proposed a stay-time estimation method. Employing these methods, we conducted an evaluation experiment and set the range value for the stay-time estimation method. When the range value was set to 4 to 8 dB, almost all the devices estimated the wait time to be within 20 s from the expected wait time. In this case, the accuracy required by users according to our questionnaire was satisfied.

In this study, we saved the observed data and then estimated the wait time. Therefore, we could not estimate the wait time immediately. Also we did not provide an estimated wait time to the users. Designing and implementing a system that estimates the wait time while measuring BLE waves and provides an estimated wait time will be the subject of further study.

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