BLE-Based Children's Social Behavior Analysis System for Crime Prevention

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Abstract. We propose an IoT-based children's behavior analysis system for crime prevention, aimed at infants and elementary school students. The system logs children's behavior with accelerometers and Bluetooth low energy (BLE). We conducted a preliminary experiment with a test application to examine whether BLE-based ID logs can be used to analyze daily social behaviors, such as how a child spent the day with his or her friends. The results suggest that the history of behavior with a child's friends was acquired accurately. Furthermore, the system could detect the period when the user (that is, a child) was with friends or not, and what kind of activity (for example, walking or staying in one place) the user was involved in.

Keywords: Bluetooth low energy · Activity log · Crime prevention · Wireless communication · Wearable device · Data visualization

1 Introduction

In Japan, most kidnappings of infants and elementary school students occur when the children are alone [9]. To address this issue, numerous tools and systems have been developed by companies for crime prevention. However, these methods exhibit various problems, such as battery consumption and large device size. For example, a crime preventing tool "Amber Alert GPS Locator" developed by "Amber Alert" [1] can track the children and can send emergency alerts to their parents. However, the system can only run for 40 h, because it acquires a global positioning system (GPS) signal and this drains the battery.

To solve these problems, we propose an IoT-based children's behavior analysis system for crime prevention, aimed at infants and elementary school students. The system logs children's behavior with accelerometers and Bluetooth low energy (BLE). The use of accelerometer logs allows the user (for example, parents) to analyze the child's behavior in a single device scenario. Furthermore, it allows the user to analyze children's social behavior, such as, whether the child' friends are nearby or not in a multiple device scenario, which enhances

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analysis. Our system uses BLE instead of GPS; therefore, it has effective battery conservation and can be used both indoors and outdoors. Moreover, the size of the battery and thus the system can be reduced when necessary. In addition, our system does not require special operation by the child.

In the following sections, we first explain the design of our system, which consists of the child's device, the parents' application, and an analysis server. Next, we describe the two experiments conducted in support of our research. We developed and executed a test application to examine whether BLE-based ID logs can be used to analyze daily social behaviors, such as how a child spent the day with his or her friends. We then implemented the system and conducted another experiment to demonstrate its capabilities in terms of detecting friends nearby the user (a child) and activity recognition. Finally, we present our future work and conclusions.

2 Related Work

Local governments and various companies have worked on the prevention of incidents such as kidnapping. Local governments employ police and volunteers to keep children secure when going to school and returning home. In addition, companies have developed various crime prevention tools, one such major tool being a personal alarm. IoT-based crime-prevention tools have been increasingly used for protecting children; for example, GPS [1], classic Bluetooth [3,12], and other communication channel-based tools have been developed.

Several systems have been developed that record the user's activities for analysis. Tsubouchi et al. [10] proposed a system that uses step information acquired from a pedometer to detect working relationships, and which can automatically write organization profiles at a low cost. Ellis et al. [4] presented a health log system for adults based on physical activity recognition using multiple wearable sensors. Zeni et al. [11] developed a method to collect the user's personal information from smartphone-integrated sensors and wearable devices. While these systems focus mainly on adults, our system focuses on children.

Various works have also focused on the location of the user. Zheng et al. [13] proposed an approach based on supervised learning to infer people's motion from their GPS logs. Their method uses common-sense constraints of the real world and typical user behavior in addition to GPS logs. Mizuno et al. [7] presented a system that tracks the user's position, which is considered to be related to the user's activity. Our system uses BLE information rather than the specific position.

In addition to GPS, which is a specialized system for position tracking, Bluetooth has attracted attention as a method of behavior tracking and activity logs; thus, many attempts at using only Bluetooth have also been undertaken. For example, Chang et al. [2] proposed a system that uses Bluetooth tags and beacons to reconstruct the user's route and uses the information to improve the user's experience.

Nishide et al. [8] used the detection history of classic Bluetooth devices to analyze a single user's behavior. Katevas et al. [6] presented a system that is able to detect dynamic groups by combining the estimated distance between people using Bluetooth data with motion activity classification. In particular, this method can estimate the stationary versus moving status of each user to detect the group's state.

Many studies in this field have been conducted using BLE, a new standard of Bluetooth with the feature of high battery conservation, in contrast to classic Bluetooth with its high energy consumption. In crowd-sensing applications, using smartphones as the main source of sensor data is difficult because of the need for downloading and installing applications, and the added burden of energy consumption. Jamil et al. [5] proposed a novel hybrid participatory sensing approach to capture large group dynamics by distributing a large number of BLE tags and smartphones to the group members. They performed a large experimental deployment with 600 tags and 10 smartphones, which was conducted during the Hajj, to prove that the approach was effective. Our approach makes use of BLE for the detection history of Bluetooth devices and their social relation, in order to analyze the child's and his or her friends' behavior.

3 System Description

Our system, as shown in Fig. 1, consists of small BLE devices for children (child's device), a smartphone application for the parents (parent's application), and an analysis server.

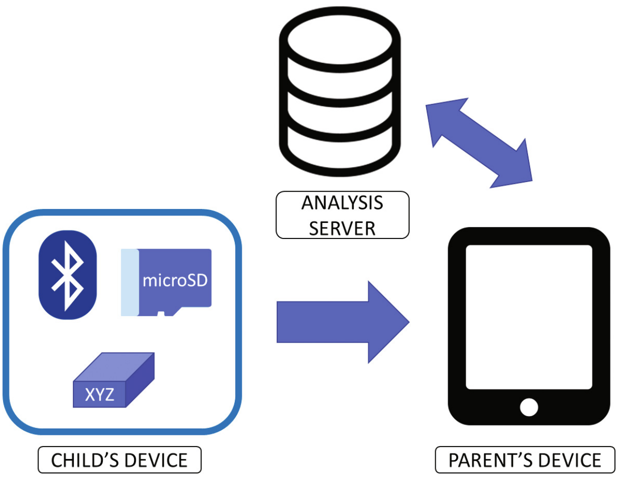

Fig. 1. System components

3.1 Child's Device

The child's device (Fig. 2) continuously reads and sends IDs via BLE. We designed the device in such a way that a child is able to carry it in his or her bag. It consists of a microcontroller (Switch Science mbed TY51822r3), an SD card as internal storage, a 3 dimensional accelerometer (Analog Devices ADXL345), and an LED. The size of the device is 4.8 × 4.5 × 1.4 cm and it weighs approximately 24 g, without the battery. Various batteries can be connected to the child's device (we used two AA batteries in our experiments). The case of the device is printed using a fused deposition modeling 3D printer. The device reads IDs sent by other Bluetooth devices, including those of the child's friends. The IDs and acceleration are stored as a log in the internal storage of the device. The device also sends out its own ID to be received by other children's devices. The IDs and relationships are registered to our system's server beforehand, and the values obtained are saved to the internal storage. The LED is used for indicating the operation status of the device.

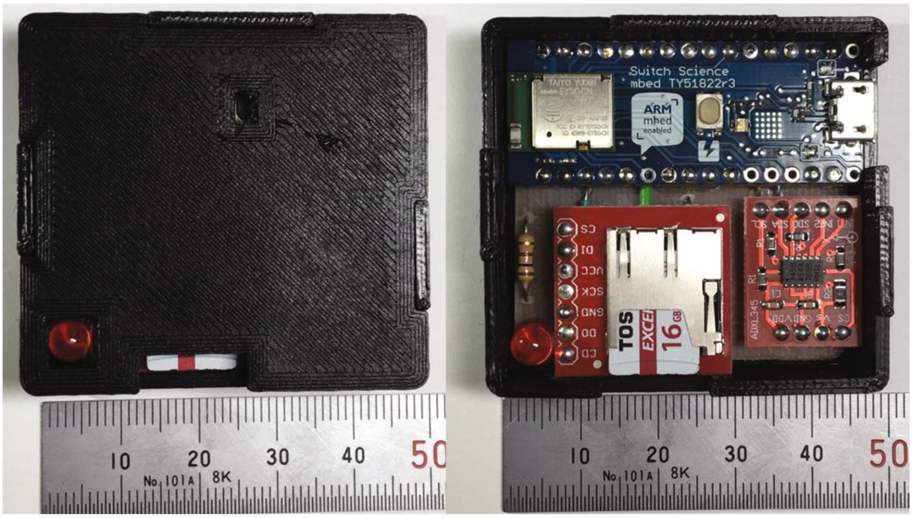

Fig. 2. Child's device (left) and inside of child's device (right)

3.2 Parent's Application

When a child returns home with their device, his or her parents connect the SD card of the device to their smartphone or tablet, and transfer the saved log to the parent's application. The parent's application has functions for visualizing the periods when the child was alone (alone periods), and for communication with the analysis server for the visualization.

In order to reduce the operational burden of checking the child's alone period, we implemented two functions in the application. The first function, namely the

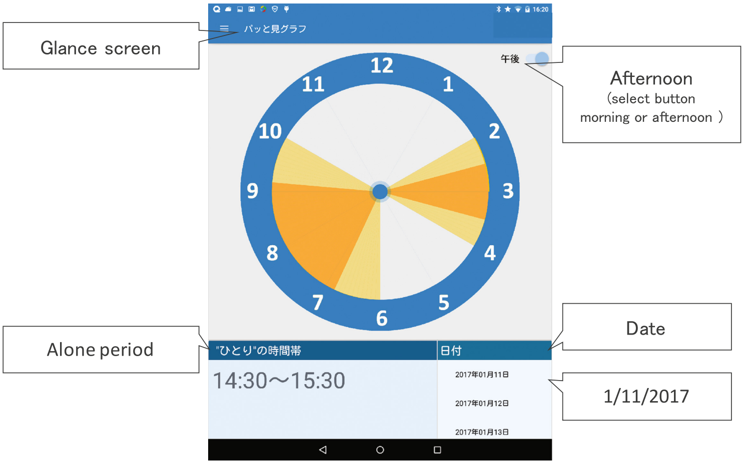

Fig. 3. Screenshot of glance screen

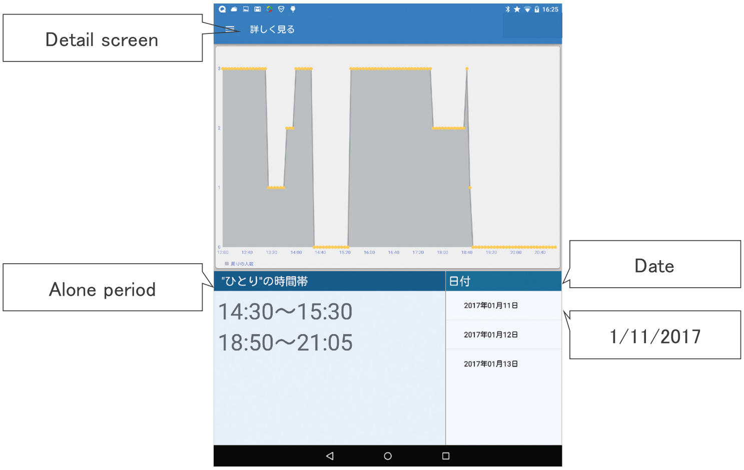

Fig. 4. Screenshot of detail screen

glance screen, displays the alone period in a simple manner (Fig. 3), where the user can check the alone period in hourly units. The purpose of this screen is to enable the parent to easily understand the alone period and reduce the burden of the parent's operation. The second function, namely the detail screen, displays the number of friends nearby in detail (Fig. 4). In each function, the user can select the item of the date they wish to view from the date column.

3.3 Analysis Server

The analysis server processes the received log and returns the total number of nearby friends per time unit time to the parent's application. The process operates as a daemon on CentOS, and we use SFTP as the transferring protocol. The following data processing is implemented in Python. Because the child's device does not have a hardware clock, it cannot record the global time when the device detects other children's devices. Therefore, the device records the time, starting with the moment when the device is activated. When the server receives the data, it converts the data recorded by the child's device into global time. Thereafter, only the log with the registered ID in the friend list is extracted as data from the log, and the total number of friends is collected for each time unit. The daily results are created and transferred to the parent's application, and the data can be displayed on each screen of parent's application.

3.4 System Scenario

Our system can be used in two scenarios: a single and multiple device scenario, as shown in Fig. 5.

- In the single device scenario, where there are no child's friends' devices in proximity, the system uses the child's movement, as analyzed by the accelerometer log, to estimate whether the child was walking or not. From these logs, the parents can determine that the child was alone, and walking or staying in one place.
- In the multiple device scenario, where there are one or more of the child's friends' devices, the system uses the IDs to estimate whether the child was near his or her friends, and also uses the child's movement to estimate whether the child was walking or staying still.

By using the system, parents can identify opportunities to provide crime prevention behavior education to their children.

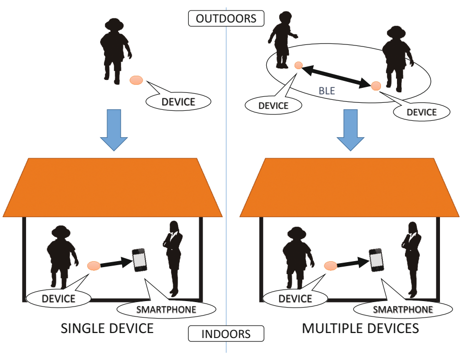

Fig. 5. Single device scenario (left) and multiple device scenario (right)

4 Preliminary Experiment

Before developing the system described in Sect. 3, we conducted a preliminary experiment to determine whether BLE-based ID logs can be used to analyze daily social behaviors, such as how a child spent the day with his or her friends. To do this, we developed a test application for an Android smartphone or tablet, which simultaneously sends and receives a BLE signal as a service, as long as the device is powered on. A total of 24 volunteers from our university, who formed teams of four to five members per team, participated in the experiment. We explained informed consent (based on the ethical guidelines of the University of Tsukuba) to all subjects and obtained their consent. We requested them to use the devices for two weeks during their school days.

Figure 6 shows the number of IDs detected by a participant's device according to time. Participants performed group work throughout the two weeks. By observing the number of IDs, we could estimate that the group work started at approximately 09:30 and ended at approximately 19:00. We could also determine that the participants had lunch with their team at approximately 13:30, because at this time there were no other friends nearby apart from members of the same team. We could furthermore observe that the participants were alone before and after the group work. In summary, the results show that by analyzing the logs of relations between people using BLE, it is possible to understand the user's activity to an extent.

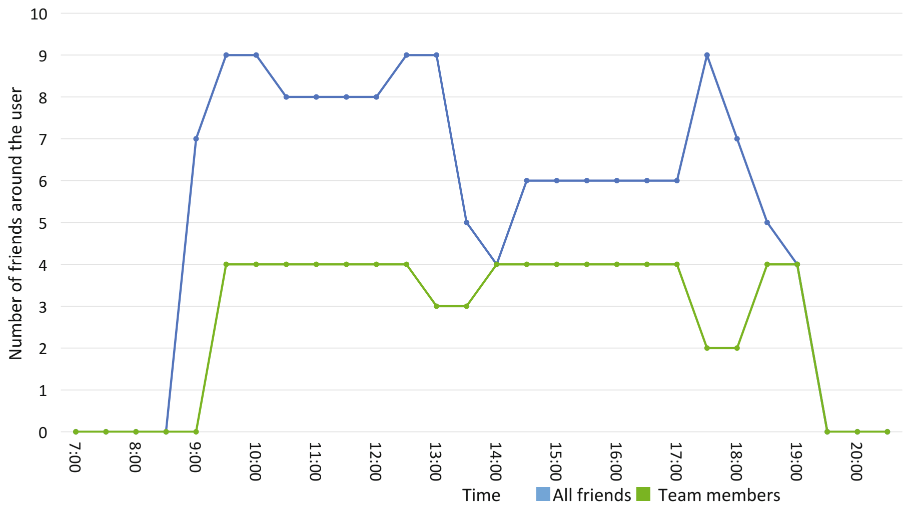

Fig. 6. Log of a day, which represents friends detected by the device of a participant

5 Experiment

As mentioned previously, the results of our preliminary experiment show that a user's activity can be estimated from the log acquired by analyzing the Bluetooth IDs near the user. However, in the experiment, the system was implemented on an Android device (smartphone or tablet); thus, it was not suitable to be held by children. For this reason, we developed the child's device which is described in Sect. 3.1, achieving downsizing and hardware robustness.

We conducted a three-day experiment using the developed device. The participants in this experiment were four male graduate students, 22 to 25 years old. They all carried a child's device during the experiment and went about their usual daily life. Since these participants were in the same research group, they spent most of their time together. After returning home, they checked the results with the parent's application. Furthermore, during the experiment, each participant recorded the names of all their friends (participants in the experiment) who were nearby in their notes every time the number of friends changed.

As an example of the results, Fig. 7 shows the number of friends nearby participant P0, which includes the number as determined by the analysis server and that recorded by the participant himself. As shown in the graph, these numbers agree. This result suggests that the system can correctly detect the period when the user is with friends or alone.

Figure 8 shows a graph representing the average acceleration per minute of P0. The graph also shows the number of friends analyzed by the system (the same data as shown in Fig. 7). We found three characteristic sections (1, 2, and 3) in Fig. 8, and interviewed P0 regarding his activities on the given day to examine the three findings.

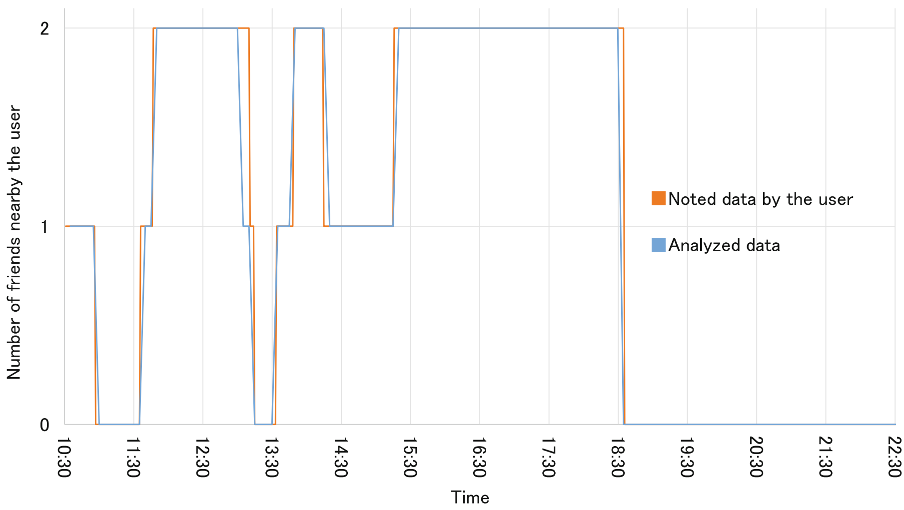

Fig. 7. Friends nearby P0 in a day

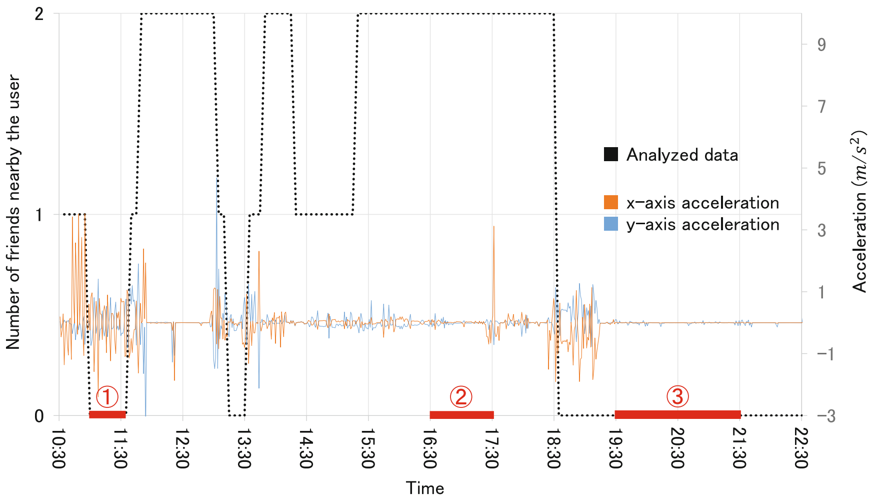

Fig. 8. Graph of the analyzed data and average acceleration per minute

1. P0 was alone between 10:50 and 11:30. However, during this period, the acceleration changed rapidly; therefore, we estimated that he was walking or running alone. P0's comments support this, as he stated that he was walking alone during this time.
2. P0 was not alone between 16:30 and 17:30. We can see there is no significant movement; therefore, we estimated that P0 was not moving. P0 confirmed this by stating that he was working at a desk with his friends during this time.
3. P0 was alone between 19:30 and 21:30. We can see that there is no significant change in the recorded acceleration; therefore, we estimated that P0 was not moving. P0 stated that he was studying alone.

We observe that we can estimate the type of activity the user was involved in by using the Bluetooth IDs and accelerometer logs. Moreover, if we simultaneously log the activity of the accelerometer, we can estimate the user's activity more precisely.

6 Future Work

We observed several problems during the experiments. In our current implementation, the user has to remove the SD card from the child's device each time they wish to transfer the saved log from the device to the parent's application, which is time consuming and troublesome. In future, we plan to enable the system to transfer data wirelessly. Moreover, because our experiment was conducted with graduate students, the logs of their daily lives show different activities to the usual activity of children. In the near future, we plan to conduct an experiment with families who have children. This will allow us to collect various data (including questionnaires) and present the log data to the parents in order to examine our design of the parent's application. Based on this new data, we plan to implement improvements to system.

7 Conclusions

In this paper, we have presented a system employing BLE and an accelerometer to analyze the social behavior of children in order to prevent crimes such as kidnapping. The results of our preliminary experiment show that using a BLE log enabled us to determine how the participant spent the day with his friends. Therefore, we implemented a child's device with BLE and an accelerometer. We conducted an experiment using our prototype of the child's device, and it was found that behavior history with the user's friends was obtained accurately. Furthermore, the system could detect periods when the user was with friends or alone, as well as what type of activity (for example, walking or standing still) he or she was involved in. The system could recognize multiple activities in both the single device and multiple device scenario. In the future, we plan to enable the system transfer data wirelessly. In addition, we plan to conduct an experiment using actual families with children.

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