System for Detecting Kindergartners' Potential Emergency Situations

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Abstract This paper describes a system for detecting kindergartners' potential emergency situations. The system consists of wearable devices for kindergartners and a computer server in the kindergarten. We designed and produced a wearable device that includes sensors for detecting potential emergencies. When a potential emergency is detected, the device sends a photo that parents can view to check what is happening at the kindergarten. We use vertical acceleration and heart rate to recognize the activity modes of the children, and experimental results show that our system enables the recognition of children's activity modes with an F-measure of over 0.8.

1. Introduction

We have constructed a system for detecting potential emergencies that kindergartners may experience by using wearable devices that enable the acquisition of not only activity information but also the biological information of the wearer. Kindergartners may find it difficult to explain a situation because they do not have the verbal ability. Our system enables photos to be taken of a kindergartner's emergency situation and sends the photos to the parents in real-time. After the fact, the system can also share with the parents information about incidents the kindergartner experienced.

For example, if parents receive an emergency e-mail from the kindergartener's device through a server in the kindergarten, they can check the situation by viewing photographs in real-time. If the situation is really an emergency, the parents can call emergency personnel. In another example, if the parents notice a scratch on the kindergartner's skin after he or she returns home, they may not be able to discover the reason due to the limited communication abilities of the kindergartner. By using our system, the parents can investigate the reason for the scratch.

A previous security camera for deterrent the crime is only for record the movies and that is not enough to remove the parent's fear of an accident of the kindergartner [1-3]. On the other hand, Child Watch Systems [4-6] enable to detect the position of child by using RFID. However, they [4-6] only detect the information of the position and cannot detect a potential emergency of the child.

To detect potential emergencies, it is important to acquire the kindergartner's activity mode, such as walking, running, sports training, playing outside, playing inside, or eating. For example, during sports training, if only one kindergartner stops moving, we can estimate that the kindergartner may have a problem and that it may be an emergency.

A previous system for identifying human activity modes can distinguish the modes of running, walking, staring up, and staring down [7]. The automatic segmentation of group activity can detect the timing of changes in the group activities of kindergartners [8, 9], but these systems [7-9] cannot differentiate between inside playing and eating. In contrast, human action recognition using acceleration with physiological data can differentiate between these activity modes [10-11]. However, it uses a wristwatch-shaped device, which is difficult to attach to kindergartners because their arms are usually very short and slim.

We developed a wearable device that has sensors, a camera, triple-axis accelerometer with dual-axis gyroscope, GPS receiver, and heart rate monitor. The main advantage of our system is that the server in a kindergarten automatically recognizes each kindergartner's activity mode by using an acceleration spectrogram and standard deviation of the heart rate. The server detects a kindergartner's potential emergency situation by searching for a child with a different activity mode from the other kindergartners. Experimental results show that our system enables the recognition of children's activity modes with an F-measure of over 0.8.

This paper is organized as follows. We present the overview of our system in Section 2, explain the development of the wearable device in Section 3, and describe the method for recognizing a child's activity mode in Section 4. We then explain the Event Checker in our system in Section 5 and present experimental results and our conclusion in Sections 6 and 7 respectively.

2. System for Potential Emergencies

An overview of our system for detecting a kindergartner's potential emergency situation is shown in Fig. 1. The wearable device regularly sends activity information and biological information from its sensors to the server in the kindergarten. If the server detects a potential emergency, the device starts to take

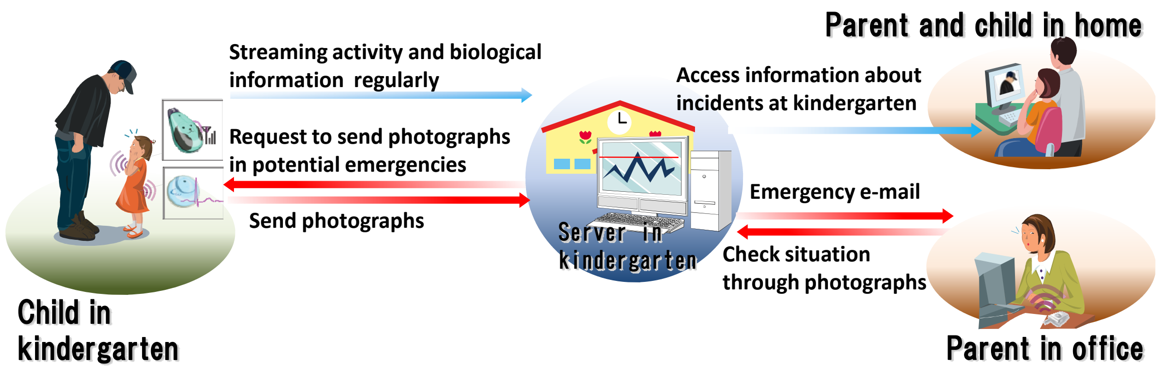


Figure 1: Overview of our system for detecting potential emergencies kindergartners may experience.

photographs and sends them to the server. The server then sends an emergency e-mail to the parents and the parents can check the situation by downloading the photograph from the server. The parents can also check the situation after returning home with the kindergartner by using a viewer that we constructed for graphically showing the incidents in a day.

3. Developing wearable device

In constructing a wearable device for a kindergartner, we made a point of using a child-friendly design that a kindergartner may delight in putting on by him or herself. The device must also be unobtrusive in long-time wear because a kindergartner may not understand the mechanism of and the reason for wearing the device. As a result of investigating children's body sizes and a questionnaire survey to parents, we decided to construct a device that is below 100 g and has a radius under 10 cm.

3.1 Child-friendly design

To construct a device having a child-friendly design, we followed three requirements.

- The device will not obstruct children's actions.
- The camera on the device can take accurate photographs of what a kindergartner is seeing.
- The device will fit closely to the kindergartner's body to properly detect acceleration of the kindergartner's body.

We sketched many designs and narrowed it down to three design candidates. Figure 2(a) shows a design called Banana. A cloth or rubber strap fits over the child's shoulder, and the body of the device (shaped like a banana) fits on the flank of the child. The Banana fits the body well, but the position of the camera is a little low, making it difficult to take photographs of situations or of the faces of adults in front of the kindergartner because a kindergartner is about 1 m tall. Figure 2(b) shows a design called Dolphin that improves on the Banana by adding a strap that wraps around the child's body, enabling the camera to be positioned higher. However, the Dolphin is difficult to adjust for different body sizes. Figure 2(c) shows a design called Omusubi. In Japanese, an omusubi is a triangular rice ball. The Omusubi improves on the Dolphin as the lengths of its straps are adjustable. Figure 3 is a snapshot of the Omusubi device that we made being worn.

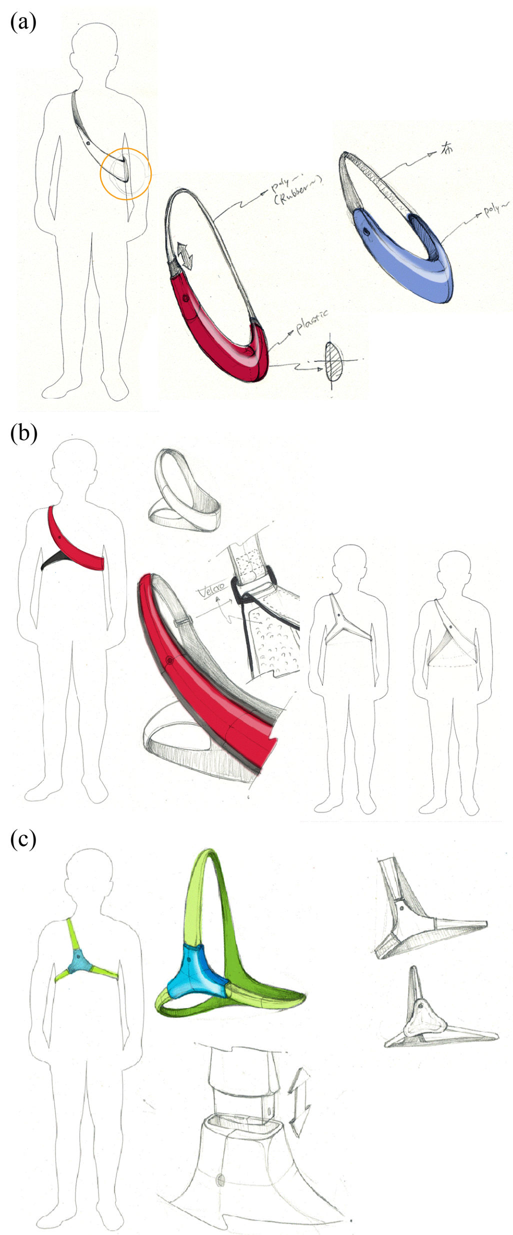


Figure 2: Child-friendly design.

Figure 3: Omusubi device.

3.2 Wireless Mesh Network

We use XBee RF modules [12-13] in wearable devices for communicating with a server. In comparison with Wi-Fi modules, XBee RF modules are lightweight (4 g) and have low power consumption (40 mA). The main advantage of using XBee RF modules is that they can organize a mesh network dynamically.

In addition, use of a Wi-Fi network is problematic because Wi-Fi networks have blind spots near building walls, restricting the coverage. A wireless mesh network does not have this problem.

Another advantage of XBee RF modules is that, by use of their mesh network function, information from a wearable device located far from the server can be communicated to the server by using a wearable device near the server as a relay point (Figure 4).

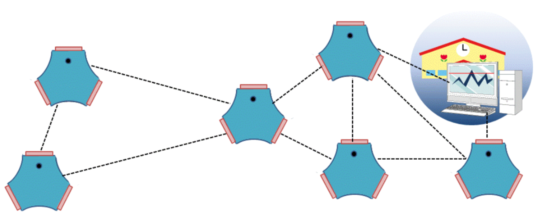


Figure 4: Mesh network function of XBee.

3.3 Device circuit

We use the Funnel I/O board to integrate the information from sensors. The Funnel I/O board can run on low voltage (3.3 V) and has a circuit for charging a lithium polymer battery. The Funnel I/O board also has an XBee socket.

We connected the Funnel I/O board to a dual-axis gyroscope with a triple-axis accelerometer (IMU 5 Degrees, SparkFun), heart rate monitor interface (SEN-08661, SparkFun), GPS (CXD2951GA, Sony), VGA camera module (SEN-09334, SparkFun), XBee RF module, and lithium polymer battery. All the sensors work on the 3.3-V voltage supplied by the constant voltage circuit on the Funnel I/O board (Figure 5). The device weighs 97 g.

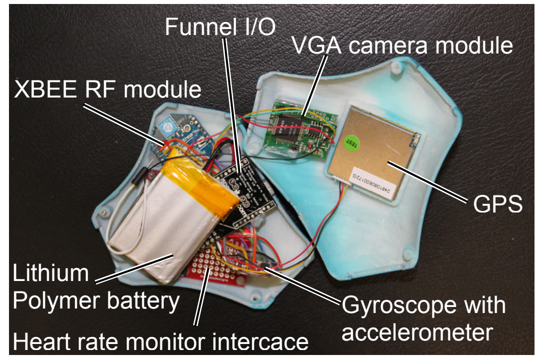


Figure 5: Circuit in device.

The heart rate monitor interface converts the signal from the Polar Heart Rate Monitor used, which is belt-shaped and needs to be fastened very tightly to the chest. Because the heart rate monitor may be too uncomfortable for kindergartners, we reformed it to enable it to be attached to the skin like a sticking plaster.

4. Activity recognition

We differentiated four types of activity mode, walking, outdoor playing, eating, and indoor playing, by using the data from the accelerometer and heart rate monitor in the wearable device. We measured the acceleration and heart rate of five five-year-old children (three girls and two boys). These measurements were conducted in a meeting room of a university, a park near the university, and a walkway in between.

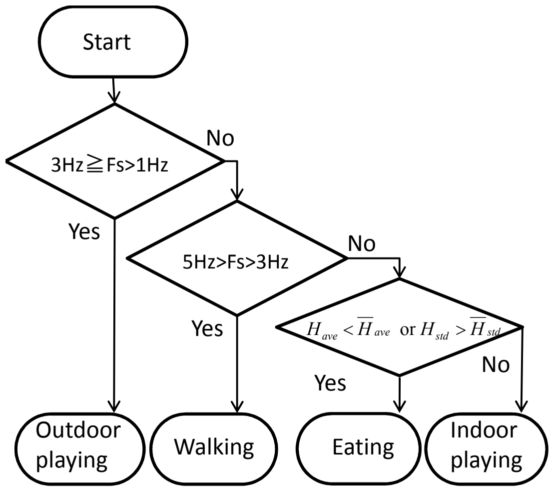
The four types of activity modes were as follows.
Walking: Children walk between the university and park while holding their parent's hand.
Outdoor playing: Children play in the park with a ball or playground equipment.
Eating: Children eat lunch while sitting on chairs in the university meeting room.
Indoor playing: Children fold origami while sitting on chairs in the university meeting room.

Our proposed algorithm for recognizing activities is shown in Figure 6. First, we differentiate walking and outdoor playing from eating and indoor playing by using the data from the accelerometer. Then we differentiate between eating and indoor playing by using the data from the heart rate monitor.

4.1 Recognition by acceleration

We use vertical acceleration to differentiate the activity mode. Figure 7 shows fast Fourier transform (FFT) spectrograms [14] of walking, playing outside, eating, and playing inside. The vertical axes indicate the frequency, and the horizontal axes indicate the time.

The spectrogram for walking (Figure 7(a)) has a peak near 2 Hz. The spectrogram for outdoor playing (Figure 7(b)) has intermittent peaks near 4 Hz. The spectrograms for eating (Figure 7(c)) and indoor playing (Figure 7(d)) do not have peaks.



Fs: Strongest frequency of vertical acceleration.
H_{ave}: Average heart rate.
$\overline{H}_{ave}$: Normal average heart rate while eating or indoor playing.
H_{std}: Standard deviation of heart rate.
$\overline{H}_{std}$: Normal standard deviation of heart rate while eating or indoor playing.

Figure 6: Algorithm of activity recognition.

To acquire the strongest frequency *Fs*, we use the autocorrelation method [15]. This method estimates the fundamental frequency (F0) from a speech signal. It is robust for signals with noise.

$$\hat{k} = \underset{k}{\operatorname{argmax}}\, X_t \cdot X_{t+k}, \qquad (1)$$

where X is one-minute-long vertical acceleration data. The optimized time lag $\hat{k}$ is one cycle of the strongest frequency *Fs*.

We differentiate among the activity modes of playing outside, walking, eating, and playing inside with the following expression.

$$M_a = \begin{cases} 1 & 5\text{Hz} > Fs > 3\text{HZ} \\ 2 & 3\text{Hz} \geq Fs > 1\text{Hz} \\ 3 & \text{Other frequency} \end{cases} \qquad (2)$$

Here, M_a is an activity mode by acceleration. M_a=1 means playing outside, M_a=2 means walking, and M_a=3 means eating or playing inside.

4.2 Recognition by heart rate

We differentiate between eating and playing inside by using the one-minute average of a heart rate H_{ave} and the standard deviation of the heart rate H_{std}. Heart rate is measured in beats per minute (BPM).

Table 1 shows the average and standard deviation of the heart rates of three children. All the subjects show the same tendencies: the average heart rate when playing inside is higher than when eating, and the standard deviation when playing inside is smaller than when eating.

Table 1. Average and standard deviation of heart rate

	Eating H_{ave}		Indoor playing H_{ave}	Eating H_{std}		Indoor playing H_{std}
Child A	100.9	<	110.1	5.699	>	4.781
Child B	100.8	<	110.0	5.710	>	4.817
Child C	97.0	<	101.1	8.863	>	5.910

To differentiate between the activity modes of eating and playing inside, we use the following expression.

$$M_h = \begin{cases} 1 & H_{ave} < \overline{H}_{ave} \text{ or } H_{std} > \overline{H}_{std} \\ 2 & H_{ave} \geq \overline{H}_{ave} \text{ or } H_{std} \leq \overline{H}_{std} \end{cases} \qquad (3)$$

Here, M_h is the activity mode by heart rate; M_h =1 means eating, and M_h =2 means playing inside. $\overline{H}_{ave}$ is the normal average heart rate in a day when M_a= 3. $\overline{H}_{std}$ is the normal standard deviation of heart rate in a day when M_a= 3.

4.3 Recognition of group activity mode

The activity recognition as described in sections 4.1 and 4.2 does not always output correct results because heart rate depends on the condition of the child.

To solve this problem, we introduce a group activity mode. This assumes that children are in the same group activity mode if they are in the same classroom. For example, if most of the kindergarteners in a

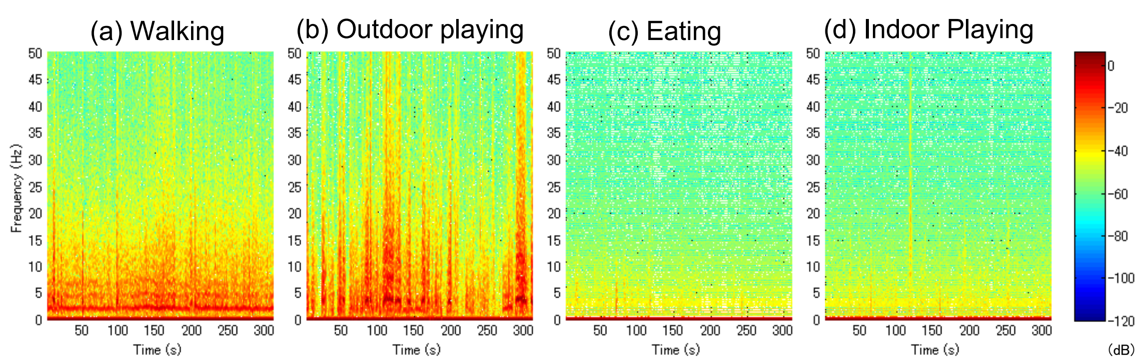


Figure 7: Spectrograms of acceleration for four activity modes.

classroom are in the eating activity mode, we can estimate that the remaining kindergarteners in the classroom will also be in the eating activity mode. We can then estimate that the group activity mode is eating.

However, the activity mode of a kindergarten class may sometimes be divided almost equally into two modes, making it difficult to determine the group activity mode. For example, when eating lunch, some kindergarteners eat very quickly and finish before their classmates, while others eat very slowly and are still eating when their classmates have finished; the former will be recognized as playing indoors, and the latter will be recognized as eating.
Accordingly, we use changing mode as the group activity mode when more than 40% of the kindergarteners are in a different activity mode.

5. Event Checker

If a parent receives an emergency e-mail, he or she can check the situation in the kindergarten by using the Event Checker in our system. The Event Checker has two modes: viewing mode and configuring mode. The viewing mode shows the events in a day structured by activity mode.

5.1 Viewing mode

Figure 8 shows a screenshot of the viewing mode. In the viewing mode, the vertical axis indicates time divided by group activity modes. Each group activity mode has more than one thumbnail photograph. Each parent only sees the photographs from the device attached to his or her own child for privacy reasons.

On the right of the thumbnail photograph is a circle with stars indicating the distance and position of other children when the photograph was taken. The distance between children is measured by the radio field intensities of the XBees in the devices. The maximum communication distance between XBees is about 30 m. Therefore, distances of 0–30 m can be detected. However, if there is an obstacle such as a concrete wall between two children with devices, the XBees cannot communicate and the distance cannot be measured.

5.2 Configuring mode

In the configuring mode, parents can configure which situations should be detected as a potential emergency and when it is necessary to send an emergency e-mail. For example, a parent may configure the following: an emergency e-mail will be sent if the child is more than 10 m from classmates while eating, and an emergency e-mail will not be sent if the child is more than 10 m from classmates while playing outdoors. When a change of group activity mode occurs, the device automatically takes a photograph and sends it to the server. The parent can also configure when the camera will take photographs and when photographs are sent to the server.

Figure 8: Viewing mode of Event Checker.

6. Experimental Results

We evaluated the performance of our system in recognizing four types of activity mode (walking, outdoor playing, eating, and indoor playing) using the F-measure, which is given by the weighted harmonic mean of precision P (proportion of selected activity modes that are correct) and recall R (proportion of correct activity modes that are identified). For the evaluation, we used 10 min of data for each type of activity mode from the measured data described in section 4 and divided it into 1-min intervals. We attempted to recognize the activity mode of each 1-min interval by our method and evaluated the performance.

Table 2 shows the results of our experiment with three subjects. For each activity mode, the F-measure is over 0.80, indicating that our system is fairly accurate in recognizing activity modes.

Table 2: F-measure for recognizing activity modes

	Outdoor playing	Walking	Eating	Indoor playing
Child A	1.00	1.00	0.80	0.80
Child B	0.90	0.90	0.90	0.90
Child C	1.00	1.00	0.90	0.90
Average	0.97	0.97	0.87	0.87

7. Conclusion

We have constructed a system for detecting kindergartners' potential emergency situations and that enables emergency e-mails to be sent from a server in the kindergarten. This system includes a device we constructed called Omusubi; it is under 100 g and fits well to a kindergartner's body. If something happens to a kindergartner wearing Omusubi, a parent can check the situation by viewing photographs taken by Omusubi. By using vertical acceleration data and heart rate data, we can recognize four types of activity mode: outdoor playing, walking, eating, and indoor playing. Experimental results showed that the F-measure of each activity mode of 3 subjects was more than 0.8.

We plan to construct about 20 devices and test this system in an actual kindergarten.

Acknowledgment

This is a contract project with Strategy Information and Communication R&D promotion programme (SCOPE) by Ministry of Internal Affairs and Communications for 2009-2010.

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