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Sleep-monitoring system for detecting infant behavior

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Abstract. This paper shows results of an experiment performed for studying infants' sleep via a novel monitoring system, comprising 16 pressure sensors beneath a mattress. We analyzed the changes in the pressure acting on the distributed pressure sensors to estimate sleeping conditions. Here, we found characteristics of the sensor data for the following three conditions: breathing, turning over on the mattress, and leaving the mattress. During the infant-sleep observation, a periodical signal appears in the pressure sensor data when the infant was breathing. Center of gravity data derived from the 16 pressure sensors drastically changed when the infant turned over on the mattress. Furthermore, the sum of the pressure data on the 16 pressure sensors decreased when the infant left the mattress. This analysis is useful for determining a threshold for detecting abnormal infant-sleep conditions.

1. Introduction

In recent years, a lack of childcare workers in Japan has become a serious problem. Childcare workers have many tasks even when children are napping. Among these, monitoring infant-sleep conditions is especially burdensome as it requires childcare workers to check whether the infants are breathing, every 10 min.

To reduce this burden on childcare workers, attempts at developing support systems such as a playmate robot have been made. Abe et al. [1] proposed a playmate robot system for playing with children that was based on an estimation of the child's mental state. Howard et al. [2], however, discussed a method for recognizing children's play by observing their motion. Although research of this kind has been conducted in the past, little attention has been paid to infants' sleep-monitoring systems. To analyze sleeping states, Kuboyama et al. [3] developed a real-time method for detecting respiration and heartbeat signals during sleep using independent component analysis on the observed signals from polyvinylidene difluoride films, which were placed beneath the bed sheet. Watanabe et al. [4] studied nonrestrictive vital bio-measurement using air mattress. Nishida et al. [5] constructed a system for monitoring human respiration and posture during sleep using a pressure sensor array comprising 221 pressure sensors attached to bed's surface. However, the measurement target for the above systems was an adult and not an infant. In this study, we target only infants and propose a system for monitoring infants' sleeping conditions at a nursery [6]. Our system can estimate an infant's sleep conditions via 16 pressure sensors in the board. We then show experimental results and analyze data [7].

2. Conversion from sensor data to weight data

Figure 1 shows the measurement system that has a sensor mat with 16 pressure sensors distributed beneath the mattress to observe an infant's sleep condition [6]. Pressure sensors change their electrical resistance depending on the amount of pressure incident upon them. A microcomputer gets its resistance as an output voltage by a resistor divider with 10-bit A/D converter [8]. The voltage data is proportional to the resistance value of the pressure sensor. A typical resistance–pressure curve for a pressure sensor is nonlinear. To calculate the center of gravity, we converted resistance data to pressure data with a conversion equation that uses some an exponential function. For rapid data analysis, we used a lookup table with all entries were calculated before beginning the monitoring step instead of performing calculations. This is because resistance data are 10-bit binary numbers; thus, we can use resistance data as a lookup table index of size 1024. The required memory space is only 8 KB if weight is represented by a double-precision floating point.

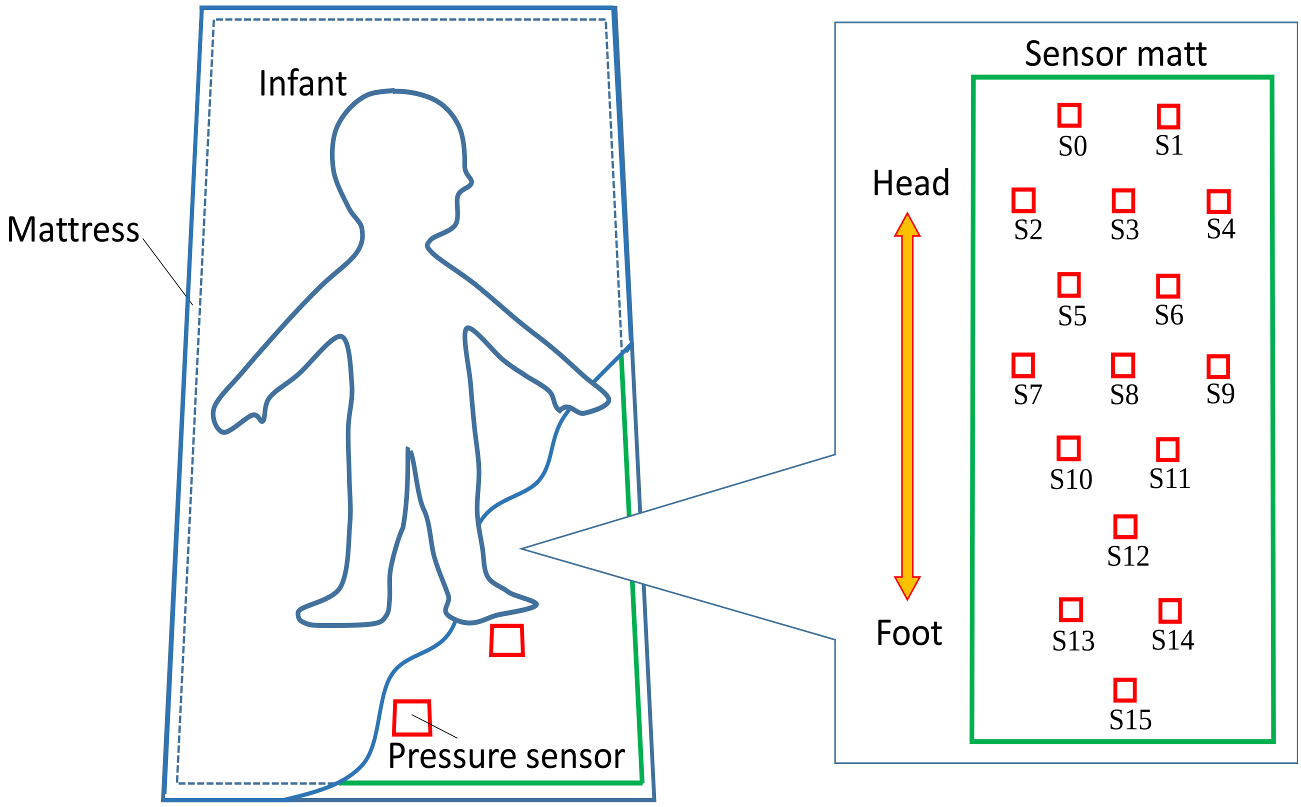

Fig. 1 Measurement system for observing an infant's sleeping conditions.

3. Estimation of sleeping condition

Our system checks infant sleeping condition using multiple detection targets and sensing methods listed in Table 1. Here we clarify three states: breathing during fast-asleep, turning over on the mattress, and leaving the mattress. All three states can be derived from the output of the 16 pressure sensors as shown in Fig. 1.

Table 1 Detection targets and methods for detecting these signals

Detection target	Sensing method
Breathing during fast-asleep	Find periodical signals that correspond to breathing
Turning over on the mattress	Center of gravity is moved drastically
Leaving the mattress	Total weight is decreased

4.Obtained data and its analysis

In this section, we show the results of experiment. A 1-year-old infant participated in the experiment as a subject. Before the experiment, we comprehensively explained the purpose of the experiment to the parent of the infant, we obtained the informed consent.

4.1 Sensor data when the infant is fast asleep

Figure 2 shows pressure sensor data for an infant that is fast asleep. Some sensors in this state receive dynamic data, which could be due to an unconscious action such as breathing. However, fluctuation may also be due to noise from the sensor or equipment. One task for future research is to distinguish whether such variation is derived from behavior or noise.

Figure 3 shows data obtained from the sensor S3, which was shown in Fig. 2. This sensor was placed under the infant’s chest. Figure 3 shows that sensor S3 receives periodical fluctuation, with an apparent fluctuation period of 3sec per cycle. Therefore, this may have derived from the infant’s breathing.

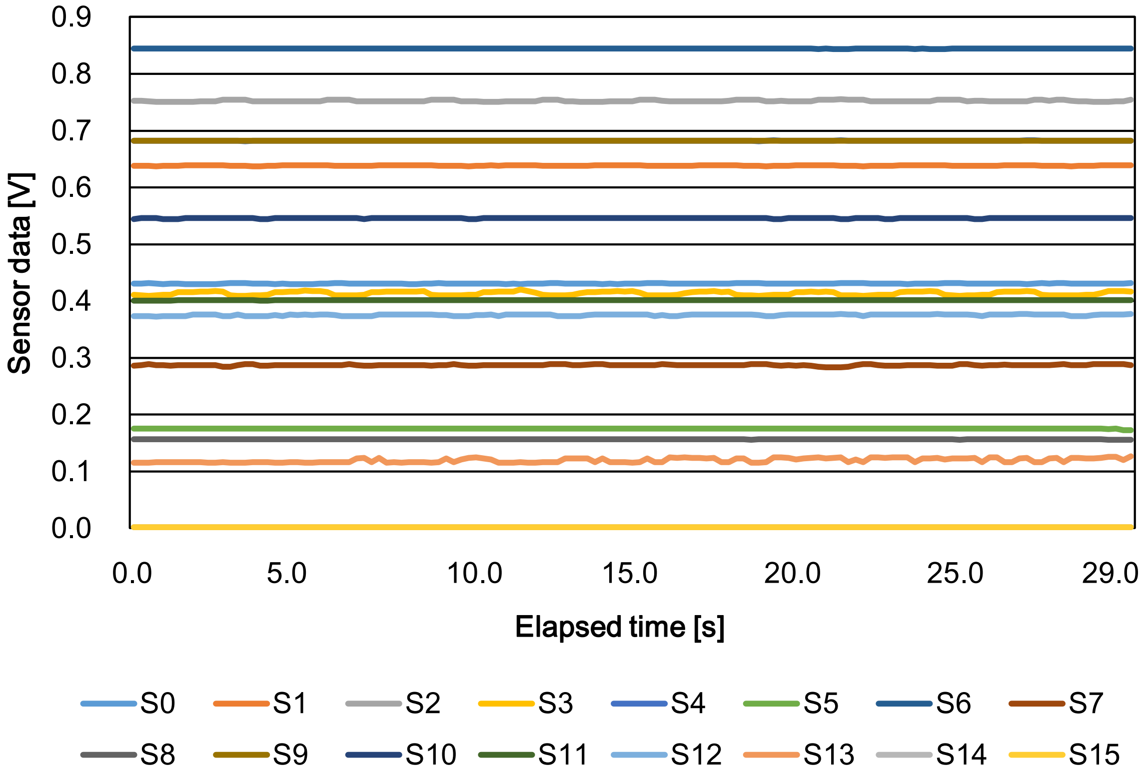

Fig. 2 Raw sensor data for a fast-asleep infant.

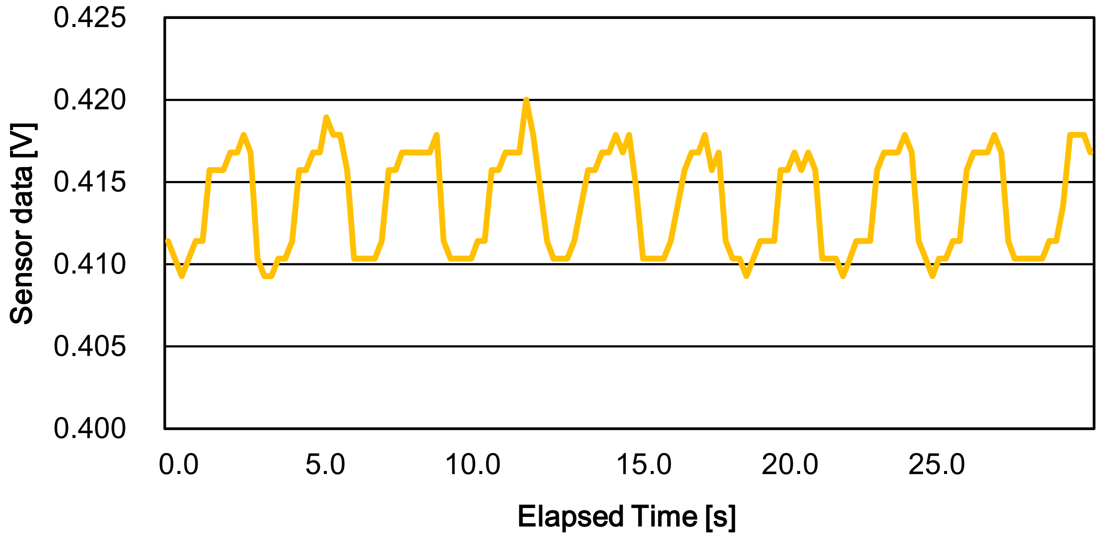

Fig. 3 Data from sensor S3, shown in Fig. 2.

4.2 Sensor data when an infant turns over on the mattress

Figure 4 shows raw sensor data when an infant turns over on the mattress and demonstrates that sensor data changes dramatically when an infant turns over on the mattress.

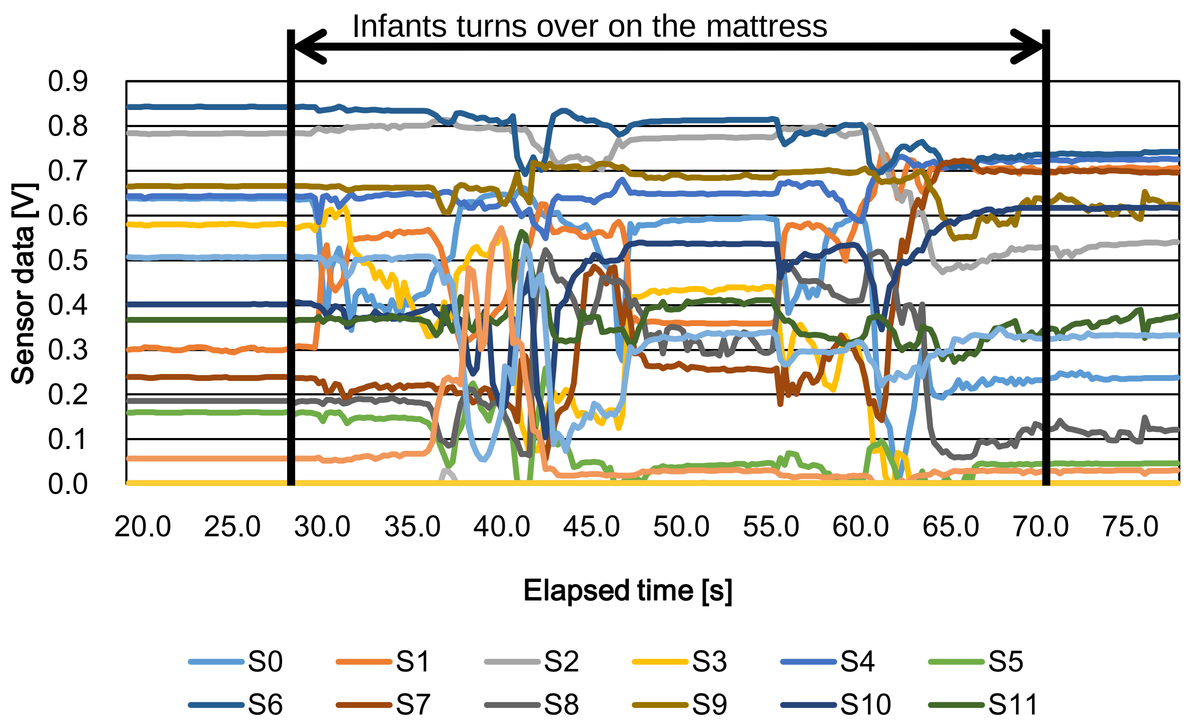

Fig. 4 Raw sensor data when an infant turns over on the mattress.

Figure 5 shows the center of gravity estimation data, with the same time scale as in Fig. 4. Data discrepancies are small when an infant is fast asleep; however, if an infant turns over on the mattress, the center of gravity moves significantly. After turning, the center of gravity's position eventually stabilizes again; therefore, we can use these data to detect an infant's movement. Summarizing, if there is a large positional difference between the center of gravity at one point of time and the average center of gravity from past data, then the system considers that the infant is moving or turning on the mattress.

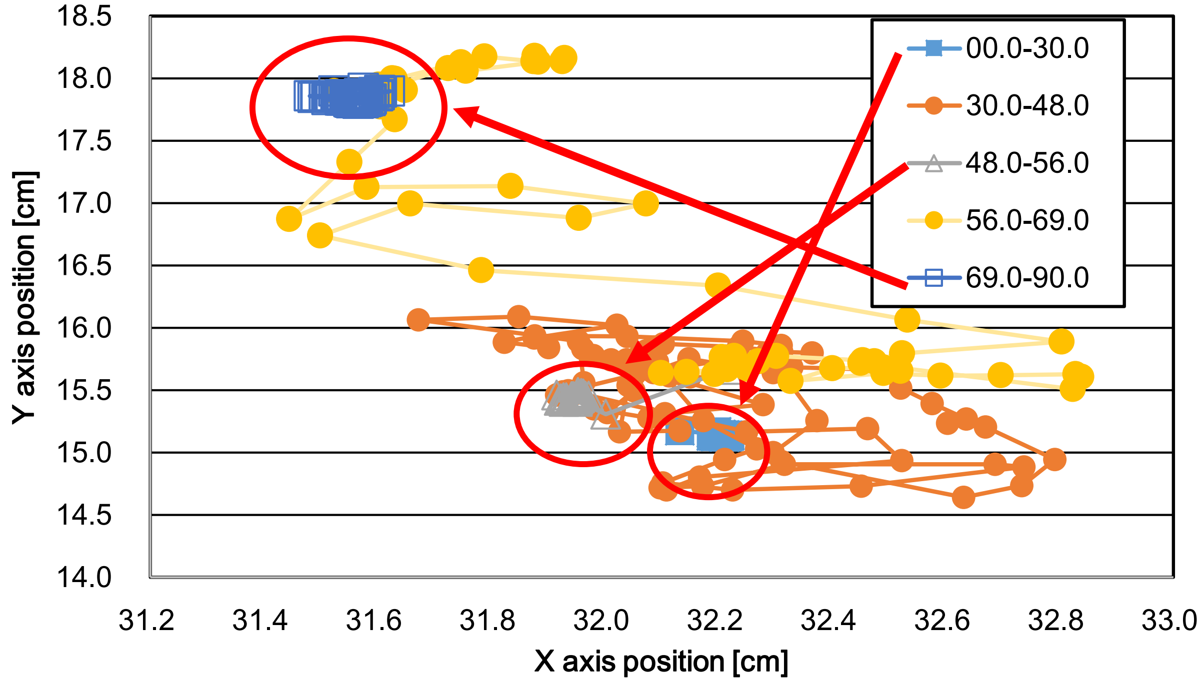

Fig. 5 Center of gravity estimation data when an infant turns over on the mattress.

4.3 Sensor data when an infant leaves the mattress.

Figure 6 shows a sum of weight data when an infant leaves the mattress.

Fig. 6 Sum of the weights.

This graph shows three situations: In the first situation, only an infant stays on the mattress; in the second situation, an infant and a childcare worker stay on the mattress and the total weight increases; and in the third situation, the childcare worker lifts the infant and leaves the mattress, wherein the total weight rapidly decreases. This type of weight variation can be used to detect an infant leaving the mattress.

5. Conclusion

In this paper, we demonstrated the results from a novel infant-monitoring system. We classified three states: breathing during fast-asleep, turning on the mattress, and leaving the mattress. The developed sensor system's observations show that periodical signals of the pressure sensor appear when the infant was breathing. Center of gravity data derived from 16 pressure sensors drastically changed when the infant turned over on the mattress. Furthermore, total force acting on the mattress decreased when the infant left the mattress. This analysis can be considered useful for deciding a threshold for detecting an abnormal condition for an infant. In future work, we would like to conduct a similar experiment with many infants participating as subjects.

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