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Emergency Condition Discrimination for Single People Using a CO_2 Sensor and Body Detectors

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***Abstract*—**The purpose of this research is to construct a watching system that monitors human activity in a room and detects abnormalities at an early stage to prevent unattended deaths of people living alone. In this article, we propose a method whereby highly urgent abnormal conditions of a person are determined by changes in the concentration of CO_2 generated from activity and respiration in a room. We also discussed the effects the amount of activity has on the determination. The results showed that this discrimination method is not dependent on the amount of activity and is effective in judging highly urgent abnormal conditions.

***Keywords*—**Abnormal conditions, multiple sensors, people living alone, respiratory arrest, unattended death, watching system.

I. Introduction

THE total population of Japan has been decreasing since 2011, and in 2017, it decreased by 210,000 compared to the previous year. On the other hand, the number of elderly people has increased by 570,000, and the ratio of the elderly population in the total population has reached a record-high percentage of 27.7% [1]. In addition, owing to changes in the composition of the population, family structures, residence statuses, economic conditions, family values and so on, single-person households are in an increasing trend throughout all ages, for both men and women. These people who live alone and do not interact with their neighbors or participate in group activities are likely to have fewer conversations compared to others. This situation is likely to lead to unattended deaths caused by, for example, lowered motivation in life and consumer damage related to money, health and loneliness, and has become a large social issue [2]. An unattended death refers to situations where a person, as a result of being isolated from society, passes away without anyone being there for them. This situation causes a delay in the discovery of their death, and there actually are cases where the body is unattended for a significant period of time [3]. Recently, there have also been increasing cases of unattended deaths of victims from disasters such as earthquakes or flooding caused by abnormal weather [4].

In order to prevent the unattended deaths of these people who live alone, measures have been taken, such as watching over them, creating a place where they can stay, and carrying out initiatives for promoting their social activity. There are many means and types of such measures, both direct and indirect. These measures include exchanging daily conversations with family members, relatives and neighbors; building a watching system in which the municipality, police, business operators and residents cooperate together; and establishing communication and supporting systems through the business activities of business operators such as power companies, gas companies, newspaper companies and cooperative associations [5]. The implementing bodies of these measures also vary from commercial and non-profit organizations to public bodies [6]. However, regular visits by these business operators or neighbors and the use of devices are limited when it comes to shortening the period until the detection of abnormal conditions or unattended death of people living alone. Against these backgrounds, there has been a demand for the construction of a watching system that detects abnormal conditions at an early stage.

Recently, IoT (Internet of Things) devices have been spreading among ordinary households, and by using them as information terminals, it will be easier to acquire environmental information such as temperature, illuminance, sounds, atmospheric pressure, etc. We think that by using the information acquired by these multiple sensors, reliable judgment can be made at an early stage.

This research aims to build a watching system that uses multiple sensors, from the standpoint of safety engineering, to monitor activity of a person living alone in a room, judge whether there are any abnormalities or danger to the person's body from the responses of a sensor, and report the results to a third party. In the past, we proposed a method based on multi-dimensional scaling [7] and a method using local outlier factors [8]-[10] as methods for discriminating between cases where a person living alone is in good condition or bad condition. These methods ascertain the daily activity patterns of a person living alone and detect moderate changes, such as health deterioration, by extracting abnormal conditions that deviate from said patterns.

In this article, we studied a discrimination method that combines CO_2 sensor responses that reflect human respiration and human body sensor responses that reflect activity in the room, to determine highly urgent abnormal conditions in cases, for example, where a person living alone collapses from cardiac arrest or cerebral infarction. First, we described how to acquire data using multiple sensors, and then examined the sensors used in determining abnormal conditions. Next, we defined three types of flags for determining conditions. Then, we

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examined the determining abnormal conditions with a time element added. Finally, we determined abnormal conditions on days different from the day the study was done previously. The results showed that this discrimination method, which takes into consideration flags and a time element, is effective in detecting highly urgent abnormal conditions, and that information can be provided to a third party.

II. Experimental Method and Data Acquisition

Fig. 1 shows the test subject's room (male, 24 years old) and the positions where the sensors were installed. The sensors used are a thermometer, a hygrometer, a photodiode for detecting lights, a condenser microphone for acquiring household noise, pyroelectric infrared sensors for detecting human bodies at the entrance and at the center of the room (hereinafter referred to as the "human body sensor"), a solid electrolyte type CO_2 gas concentration meter (hereinafter referred to as the "CO_2 sensor"), and a lead switch for detecting the opening/closing of the entrance door. The measurement was carried out by extracting the subject's activity in the room using multiple sensors installed to positions indicated in Fig. 1. The sensors were installed on the ceiling of the room, so that they would not interfere with the daily life of the subject. The sensor responses were sampled and imported to a PC every 10 seconds. The response of the lead switch was imported as a result of determination as to whether the subject is inside or outside the room. With regard to the determination of whether the subject is inside or outside the room, the subject was determined to be inside the room if the human body sensor at the entrance responded within 10 seconds after the door has closed, and if there were no responses outside the room.

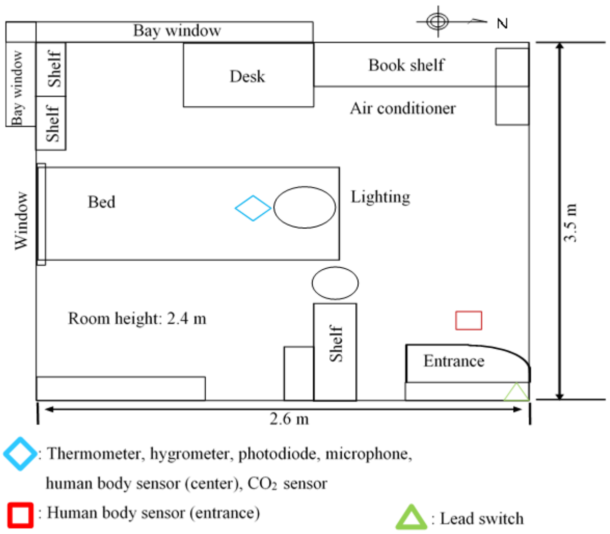


Fig. 1 Test subject's room and sensor locations

For the abnormal condition, we simulated a condition where the subject stopped breathing as a result of cardiac arrest or cerebral infarction after carrying out usual activity. For the occurrence of the abnormal condition, we assumed two patterns: when there is less human activity in the room, and when there is more. Fig. 2 shows a series of activities carried out in the experiment. After the subject carried out his usual activity, if there was low activity, we had the subject continue as normal. If there was high activity, we had him continue in-room exercises such as stretching, muscle training, and walking. After that, we had him simulate a respiratory arrest. In order to simulate a respiratory arrest, we connected a hose to the subject's mouth and had him breathe through his mouth, and laid the hose to outside the room so that the respiration will not affect the CO_2 concentration in the room.

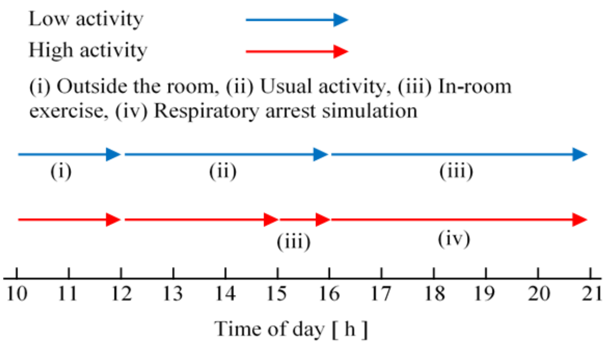


Fig. 2 Series of activities carried out in the experiment

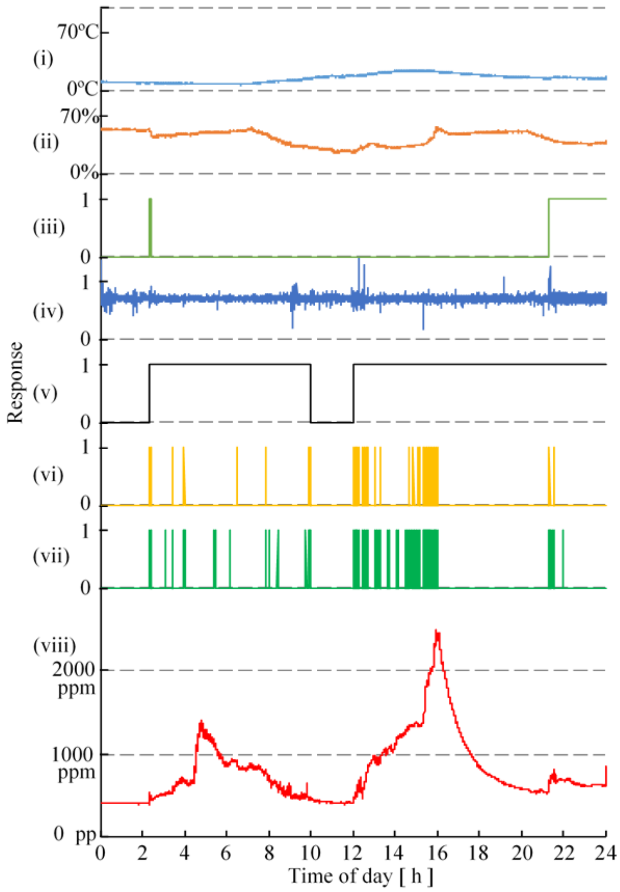
Fig. 3 shows the responses of the sensors in the case of high activity, which were measured on November 19, 2017. The subject entered the room at 2 o'clock at night and went to sleep. He woke up at 9 o'clock in the morning and went out around 10 o'clock. He re-entered the room at 12 o'clock and spent time doing his usual activities until 15 o'clock, so the CO_2 concentration (viii) increased gradually during this time period. From 15 o'clock to 16 o'clock, he did some in-room exercise as a load, so the CO_2 concentration in the room increased sharply. After that, from 16 o'clock to 21 o'clock, he simulated a respiratory arrest. Because there was no respiration, the CO_2 concentration dropped suddenly. While he was simulating a respiratory arrest, there were no sensor responses from the human body sensors at the entrance and at the center. It was indicated that he was inside the room for the determination of whether the subject is inside or outside the room. A similar trend was also observed in a case where there were low activity (January 5, 2018). From the above, we decided that the responses of human body sensors and a sudden drop in the CO_2 concentration in the room to be the elements for determining abnormal conditions.

III. Definitions of Flags for Discriminating Conditions and Discrimination Method for Determining Abnormal Conditions

On the basis of the output of the CO_2 sensor and human body sensors, we considered three types of flags for determining the subject's condition: "Alarm" for indicating highly urgent abnormal conditions, "Pre-Alarm" for indicating abnormal conditions where attention is needed, and "Safe" for indicating normal conditions.

Fig. 4 shows the responses from the CO_2 sensor - the results for when there was high activity after 12 o'clock in the experimental environment given above and where there were low activity. The CO_2 concentration tends to converge to 400 ppm when there were no people (from 10 o'clock to 12 o'clock when the subject was out), and 700 ppm when the subject was sleeping (from 2 o'clock to around 8 o'clock). After 16 o'clock when the subject simulated a respiratory arrest, the CO_2 concentration decreased rapidly and reached a value close to 400 ppm, which is the value for when there are no people. From the results above, we decided the abnormal element for the CO_2 sensor to be when the subject is inside room and the CO_2 concentration is 700 ppm or less, or when the inclination of decrease is -0.05 ppm/s or less. The limit value, 700 ppm, was determined from the average and the minimum values of CO_2 concentration during when the subject was sleeping and at rest, as shown in Fig. 4. The inclination of decrease was determined from the change between the time when respiratory arrest has occurred and the time when the concentration has decreased to 700 ppm. Furthermore, the CO_2 concentration in the room fluctuated consistently because of the effects from outside air, etc., and it did not stabilize. To resolve this problem, we smoothed the CO_2 sensor measurements by taking the 15 points moving average. We decided the abnormal element for the human body sensor to be when there are no responses in a fixed period of time. We set the fixed period of time to 4 minutes (the time when the mortality rate from respiratory arrest becomes 0%,) on the basis of the "Golden Hour" [11], which is a guide for saving lives. On the basis of the above, we decided to set one flag when the CO_2 sensor and the human body sensors both indicated that there is an abnormality, and defined the abnormal elements for determining abnormal conditions as described below. We defined "Alarm," which indicates highly urgent abnormal conditions, to be a case where there are 16 or more abnormal elements in the immediate 180 seconds (considered to be the time when brain cells start to die) [12], and "Pre-Alarm," that indicates abnormal conditions where attention is needed, to be a case where there are 12 to 15 abnormal elements.

Fig. 5 shows the results of flag calculation (a) shows the results for when there is low activity (Jan. 5, 2018), and (b) shows the results for when there is high activity (Nov. 19, 2017). In the case of (a), where there were low activity, the system continuously determined it to be an Alarm after 16 o'clock, when the subject started to simulate a respiratory arrest. There also had been sporadic occurrences of Alarm and Pre-Alarm flags starting from when the subject entered the room until when he simulated a respiratory arrest. In the case of (b), where there was high activity, the system continuously determined it to be an Alarm after 16 o'clock, when the subject started to simulate a respiratory arrest, same as for (a). However, after 17 o'clock, the system determined it to be a Pre-Alarm or Safe condition, in spite of the subject's respiration having stopped. This is most likely because the decrease in the CO_2 concentration slowed down and the abnormal elements did not meet the conditions for an Alarm, which made the responses sporadic and left the system unable to detect abnormal conditions.



(i) Thermometer, (ii) Hygrometer, (iii) Photodiode, (iv) Microphone, (v) Inside/outside the room, (vi) Human body sensor (entrance), (vii) Human body sensor (center), (viii) CO_2 sensor

Fig. 3 Responses of the sensors in the case of high activity (Nov. 19, 2017)

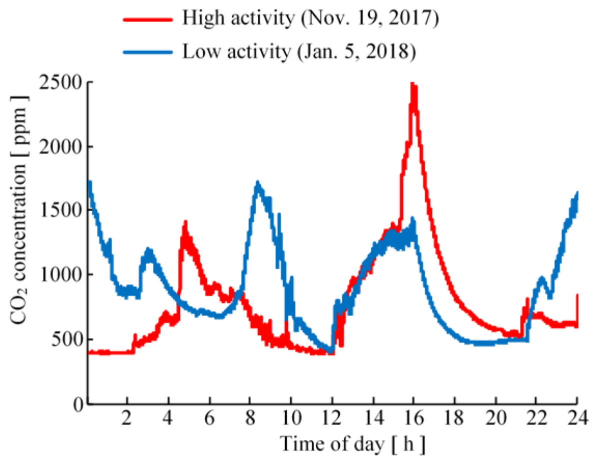
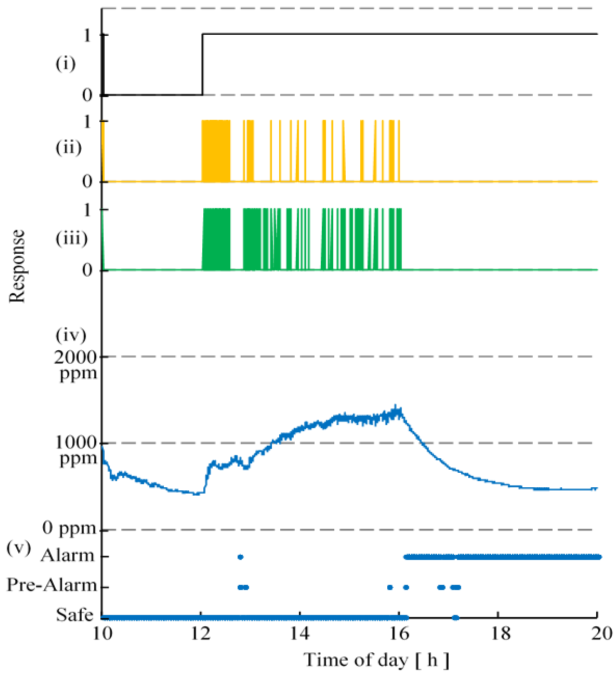
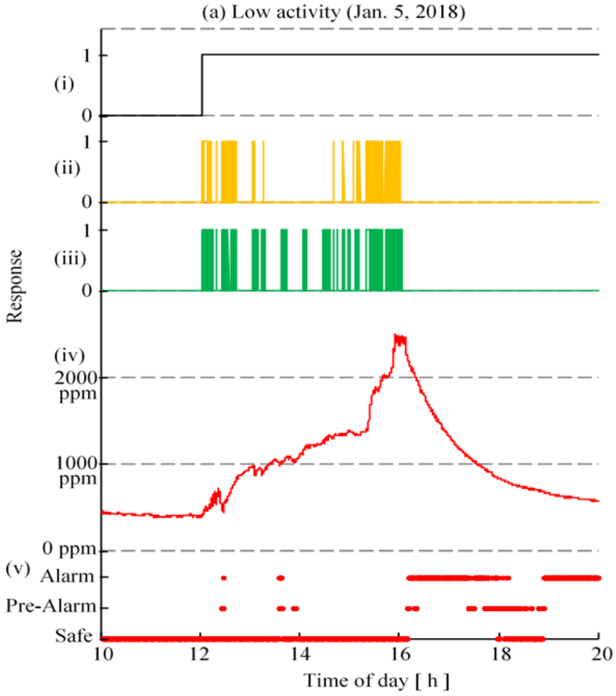


Fig. 4 CO_2 sensor outputs



(i) Inside/outside the room, (ii) Human body sensor (entrance), (iii) Human body sensor (center), (iv) CO_2 sensor, (v) Flag calculation result

(a) Low activity (Jan. 5, 2018)



(i) Inside/outside the room, (ii) Human body sensor (entrance), (iii) Human body sensor (center), (iv) CO_2 sensor, (v) Flag calculation result

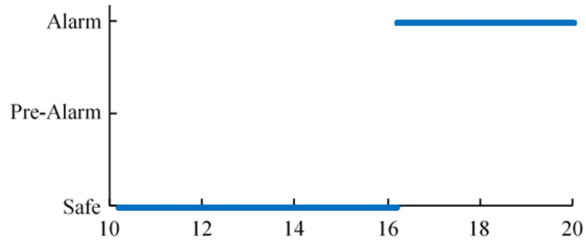
(b) High activity (Nov. 19, 2017)

Fig. 5 Flag calculation results

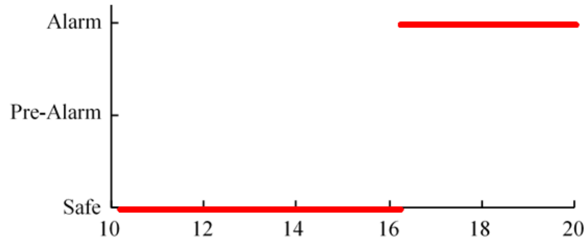
IV. Determining Abnormal Condition with a Time Element Added

Taking into consideration the results of the discussion in the previous chapter, we added a time element for the determining abnormal conditions. With this process in place, the system determines the condition to be an Alarm condition if the Alarm flags continues for the immediate 180 seconds. In addition, if an Alarm condition has continued for the immediate 4 minutes (the "Golden Hour" described above) and it changed to Pre-Alarm or Safe conditions, it is regarded as a sporadic output and the Alarm continues.

Fig. 6 shows the determination results for abnormal conditions that were obtained by adding a time element to the flag results given in Fig. 5 (a) shows the determination results for when there is low activity (Jan. 5, 2018), and (b) shows that for when there is high activity (Nov. 19, 2017). Both results indicated that the system continuously determined it to be an Alarm condition after the start of respiratory arrest. In both cases, there were no more erroneous determination seen in flag calculation results, and highly urgent abnormal conditions could be detected correctly.



(a) Low activity (Jan. 6, 2018)

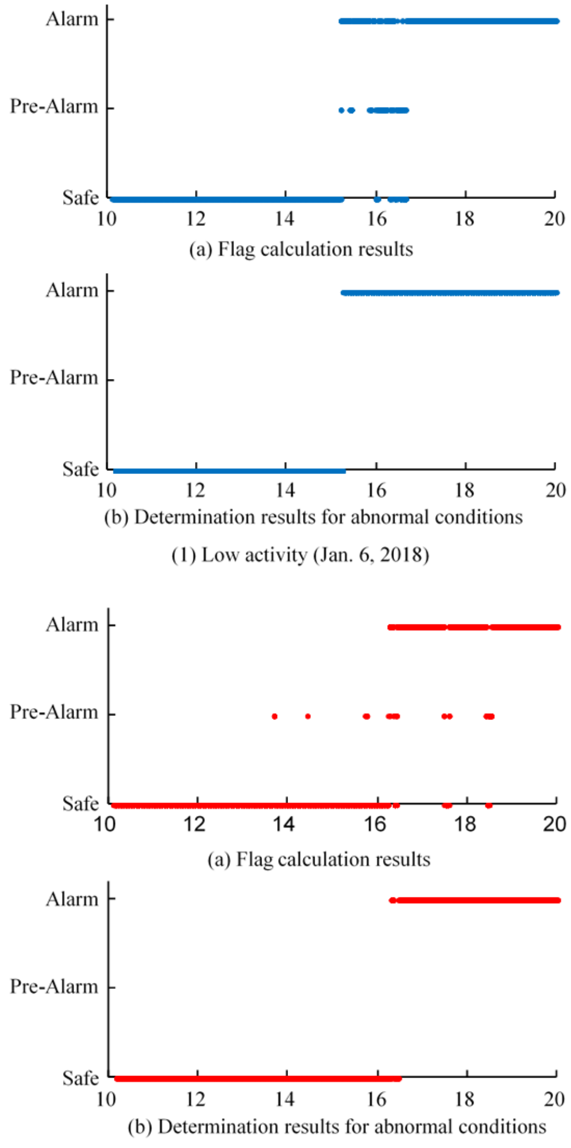


(b) High activity (Nov. 19, 2017)

Fig. 6 Determination results for abnormal conditions

In order to check that the proposed method for determining abnormal conditions also works during other days, we conducted experiments on day different from the days the study was made previously, and examined the determination method for abnormal conditions.

Fig. 7 shows the results for (1) when there was low activity (Jan. 6, 2018), and (2) when there was high activity (Oct. 31, 2017). For both cases, (a) shows the results for the flag calculation and (b) shows the determination results for abnormal conditions. In the case where there as low activity, the subject simulated a respiratory arrest from 15 o'clock. Both results indicated that the system continuously determined it to be an Alarm condition after the start of respiratory arrest. As discussed above, in both cases, there was less erroneous and abnormal conditions determination seen in flag calculation results, and highly urgent abnormal conditions could be detected.



(a) Flag calculation results

(b) Determination results for abnormal conditions

(1) Low activity (Jan. 6, 2018)

(a) Flag calculation results

(b) Determination results for abnormal conditions

(2) High activity (Oct. 31, 2011)

Fig. 7 Determination results for flag calculations

V. Conclusion

We proposed a method for determining highly urgent abnormal conditions of people who live alone, by mainly using a CO_2 sensor and human body sensor responses coming from multiple sensor responses. As a result of applying this method for cases with different amounts of activity, we clarified the following:

1) We proposed a method for determining highly urgent abnormal conditions such as a respiratory arrest, by using a CO_2 sensor and human body sensors;
2) In determining abnormal conditions, we proposed three types of flags, "Alarms," for indicating highly urgent abnormal conditions; "Pre-Alarms," for indicating abnormal conditions where attention is needed; and "Safe," for indicating normal conditions, and a time elements; and
3) As a result of conducting determination for other days by simulating a respiratory arrest using the proposed method for determining abnormal conditions, we could determine abnormal conditions regardless of the amount of activity, indicating that this method is valid.

By using the method proposed in this article, it became possible to determine highly urgent abnormal conditions of people living alone, and to provide information to a third party.

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