A Study on Combined Use of Contactless Sensors to Watch over the Safety and Health of Living Alone

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***Abstract*—In a super-aged society, medical services for health management have various problems. To solve these problems, it is desirable for all generations, including the elderly, to be self-reliant and maintain their health. In this paper, a system is proposed for everyone to actively manage their health. This system uses various contactless sensors to monitor the health of the elderly living alone and monitor and store the biometric information of the person. By comprehensively analyzing these sensor data, the system assists people and observers to easily recognize changes in the physical condition of the target person. Further, the system facilitates providing information to distant healthcare professionals when people receive medical care at home. The system prototype was created to demonstrate this mechanism. Also, the system conducts preliminary experiments and confirmed that the models and algorithms worked as expected. In the demonstration experiment, the observation target was observed using a millimeter-wave sensor and a multi-channel gas sensor, and both were integrated. As a result, the system presents changes in the observation target in detail.**

***Index Terms*—Ambient Assisted Living (AAL), living alone, multi-sensor data fusion, smart home, watch over**

I. Introduction

In recent years, the world population increasing year by year. At the same time, the ratio of older people in the population is increasing. Similarly, the percentage of single-person households is increasing, especially in developed countries. It predicts that the spread of these trends will promote the evolution of medical technology and the diversification of lifestyles.

In general, living alone poses few health risks due to living alone. However, if an accident such as a sudden illness occurs while living alone, the risk of falling into a life-threatening situation is high. Also, the absence of a cohabitant increases the risk of being unaware of changes in the physical condition and disease progression.

Therefore, recently, remote monitoring research using an internet of thing (IoT) sensor called mHealth is conducting to watch the safe life of people living alone, and it has spread to the real world. Also, policy systems and services such as ambient assisted living (AAL) have become popular.

AAL is a concept that uses variable sensors and artificial intelligence (AI) to support the lives of people living alone, the elderly, and people with disabilities. The key to the concept is to provide functionality that meets the needs of the monitored party while respecting the monitored party's privacy. To do so, it needs to install systems and products in their living spaces. A house with these functions and services is called a smart home.

In the conventional monitoring system, a sensor device is attached to the human body to monitor the monitored person. By using them, it is possible to accurately detect the biological information and behavior of the target person. As a result, it allows for precise oversight. However, these methods have problems such as troublesome wearing by a watched person and insufficient consideration of privacy.

Therefore, in this paper, a method is proposed that keeps the watched person observable with a long-distance without using a wearable device. Fig. 1 shows an image of a person looking at multiple contactless sensors. In this method, a plurality of types of contactless sensors is used in combination to continuously acquire movements, lifestyle patterns, and rough biological data of the person.

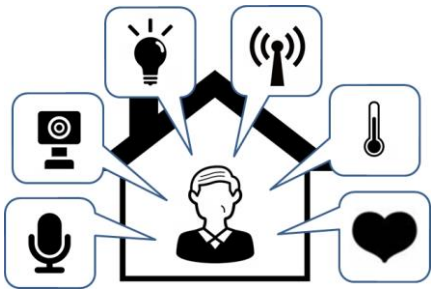

Fig. 1. Watching an elderly person with contactless sensors

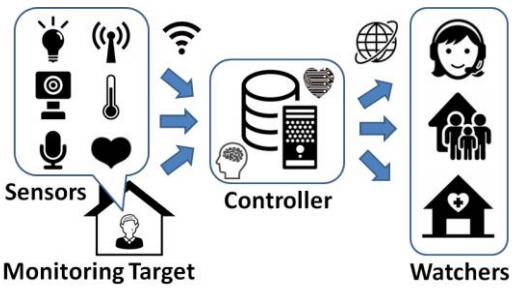

Fig. 2. Design of health and safety monitoring system

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Fig. 2 shows the overall structure of the system for watching over living alone in this system. The proposed system analyzes the data acquired by these sensors, and the system calculates the physical and mental health of the person and the risk of illness. As a result, the system presents the person's information to the monitored person and the observer-based on this calculation.

The advantage of this mechanism is that it can be watched with privacy in mind so as not to interfere with the life of the watched person. In this system, the monitored person selects the information to monitor the person. The method of the person to present living information as needed is useful for both the person and the monitoring person.

II. Related Work

Many research projects are seeking ways to provide home health care to distant people. In research on methods for acquiring human activity data and biometric data using sensors, various methods are used as data acquisition methods. Up until now, we have used a sensor attached to the human body to acquire data. These sensors can connect to the internet via IoT devices and collect sensor data on the server. Research is underway to analyze these data and understand the condition of the observation target.

In-home health research, four issues are considered important. The first is research on how to use sensors to capture human activity and biological data. There are many studies and practical applications of wearable devices that can be worn on the human body. There are various studies on how to present information to the observation target. Next is a study on how to collect and analyze the acquired data. Also, the question is who and how to present the information that results from analyzing the data. Finally, it is a study to realize the reuse of knowledge by utilizing the big data and information obtained by those mechanisms. So far, some researches have been undertaken to monitor people driving vehicles with various sensors and to provide useful information for safe driving [1]-[3].

There are various researches to realize human health by observing people and the environment. Yatsuda *et al*. proposed a method to prevent heatstroke in elderly people with sensors and robots [4]-[6]. In that method, the risk of heatstroke is calculated based on the observation result of the temperature and humidity sensor installed indoors, and a warning is issued using a communication robot.

Many researches on sensor network communication methods are also underway. Corchado *et al*. proposed a decentralized remote monitoring system aimed at improving health care and supporting home dependents [7]. In this proposed system, the ability to recover from communication errors is improved by using various wireless sensor networks for distributed communication. Surie *et al*. introduced the results of an operation experiment of a detection system in which multiple sensors are connected by a ZigBee wireless sensor network [8]. In their experiment, they confirmed that sensors in eight different locations were able to transmit and receive data almost normally.

Much research has been done on the surveillance of the watched elderly. Robert etc. Investigated the perceptions, attitudes, and concerns of older people about remote monitoring using wireless sensor network (WSN) technology [9]. As a result, older people say it's more important to be independent than to disclose the privacy of health data. There have been many studies on methods of calculating risk by detecting human movement. Among them, several methods have been proposed for detecting the sudden fall of a person in real-time [10], [11]. This is so-called crisis detection.

Recently, research is also progressing on methods for watching persons without wearing sensors [12], [13]. Lin *et al*. reviewed the recent developments of a contactless vital sign (heartbeat and respiration) detection system using a low power microwave radar sensor [14]. Bose *et al*. showed a system that uses sensors to continuously monitor and maintain the respiratory rate of a monitored patient [15]. Suzuki *et al*. showed algorithms for detecting objects from millimeter-wave radar measurement results [16].

III. Type of Contactless Sensors

This section explains the contactless sensor used in the system proposed in this study. Contactless sensors are developing technologies that accurately measure biological data such as the heart rate and body temperature of the watched person. If they want to accurately measure their biometric data, they should wear contact sensors on their bodies. However, when people wear contact sensors to watch over, their quality of life is impaired, and they feel the stress being monitored. Therefore, in this study, to solve these problems, contactless sensors are used only to observe the monitored person's behavior and biological information.

There are two types of contactless sensors: passive sensors and active sensors. After explaining each one, we describe how to use them appropriately depending on their characteristics. It also explains the benefits of using these sensors together.

A. Active Sensor

An active sensor has the function of transmitting light, radio waves and sound waves, and the function of receiving it. The sensor observes the target by sending waves to the observation object and collecting data on the bounced waves. Currently, active sensors are used in various situations in daily life. For example, it is possible to detect an event leading to an accident by monitoring the front and surroundings of the vehicle with an active sensor while the vehicle is driving and take warnings or preventive measures before the accident occurs. By using active sensors for remote sensing, you can continue to observe people and objects that are far beyond the distance and range of the naked eye.

The disadvantage of active sensors is that they need to transmit light, radio waves, and sound waves, and therefore require some energy for measurement. Also, the active sensor is relatively large, as it must have both a transmitter and a receiver. Furthermore, it cannot be said that the transmitted light, radio waves, and sound waves

emitted by the active sensor do not affect the human body. Also, if the same type of active sensor is used in the measurement area of the sensor, the transmitted and received data may interfere and the correct observation may not be possible.

B. Passive Sensor

A passive sensor collects target data by detecting vibration, light, radio waves, sound, etc. emitted from the observation target. Unlike active sensors, it does not affect objects. The most familiar passive sensor is video acquisition by cameras. However, with a visible light camera, observation data related to the environment such as outdoor and indoor temperature and humidity is also acquired with a passive sensor. Seismometers are also passive sensors. Besides, passive sensors generally do not require a power source and are often simpler in structure than active sensors.

The disadvantage of passive sensors is that the physical range that can be observed is limited. When measuring the environment, accurate measurement results are not possible unless the object is close. The visible light camera cannot shoot in locations without ambient light.

C. Combined Use of Active and Passive Sensors

These active and passive sensors have advantages and disadvantages, respectively. If they understand these characteristics clearly and use both types of sensors together, they can observe various data. It is also important to install them in appropriate locations according to their characteristics. It is possible to classify the situation using a lot of data obtained from these sensors.

When using an active sensor and a passive sensor together, it is necessary to consider that what is transmitted from the active sensor does not adversely affect the observation results of the passive sensor. For example, if it uses active and passive audible sensors at the same time, the passive will capture the waves emitted by the active. However, if it can control the data transmission from the active sensor, the data is useful for observation. For example, they can use them as large active sensors by observing sound using multiple speakers and multiple microphones.

IV. System Design

This section describes the design and functionality of the surveillance system using the contactless sensor proposed in this article. The functions provided by this system are to grasp the health condition of the target from the sensor data and to provide appropriate information to the person who is watching it. The elements necessary to realize these are a data collection mechanism that observes the target using sensors, a mechanism that analyzes the observed data and classifies the target state, a mechanism that advises the person according to the state of the target person, There are four elements of the mechanism that provides information to the person watching depending on the condition.

Fig. 3 shows the components and configurations installed in the smart home in order to observe the safety and health of the watched person. This system introduces an algorithm for determining two states based on data acquired from a plurality of sensors installed in each room of a smart home. By using this, it is possible to obtain the distance between the sensor and the observation object, the positional relationship, and the relative velocity. Furthermore, in recent years, research on vital sensing that measures human heart rate and respiration using radar sensors is underway. Using an optical camera to detect human movement and facial expression, to detect temperature with a far-infrared sensor, to obtain voice data and living sound using a microphone, and to analyze components in the air in the room with a gas detection sensor.

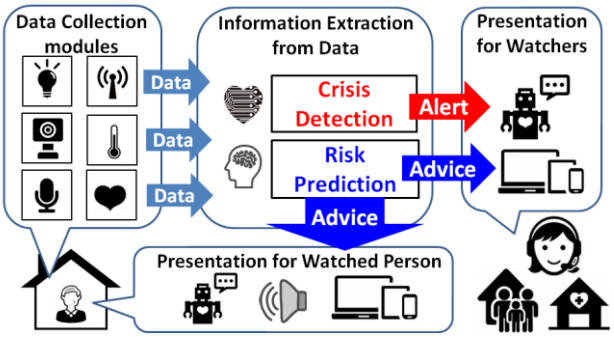

Fig. 3. Configuration of health and safety monitoring system

The first is an algorithm that determines whether a watched person is in a dangerous state. This alerts the watched person when the person determines unusual behavior or unusual health status. The watchers who have received this alert is asked to take a method to confirm the safety of the person.

Another condition is to judge a person's quality of life. For example, if the result of analyzing sensor data that can observe the movement of the person shows that the person has remained in the living room and has not moved throughout the day, it provides advice that encourages the person to exercise. This information is shared by both the watched person and the watchers. That is, the system watches the person's lifestyle and announces it to the watchers.

A. Sensors for Data Collection

In this system, the watched person wears no sensors to acquire behavioral and biometric data. Instead, the system only uses contactless active and passive sensors. Active sensors measure the environment by emitting waves and observing reflected waves. The waves emitted by sensors are sound, light and electromagnetic. Active sensors used in this system include sensors that measure distance by emitting ultrasonic waves, LiDAR (Light Detection and Ranging) sensors that emit infrared rays and radar sensors that emit millimeter waves and microwaves. The passive sensors used in this system include visible light cameras and infrared cameras, microphones, thermography, gas sensors for observing air components, pressure sensors,

potential sensors, light sensors, and vibration detection sensors.

The system uses a non-contact sensor to capture all kinds of data such as the movement of the target's body in each room, the sounds and breaths emitted by the target, heartbeat and body temperature, environmental sounds, room temperature, and humidity. The system's sensors monitor the status of subjects installed on the system in all areas except limited private areas. The system continues to send the observation data acquired by these sensors to the controller in real-time over the internet.

B. Controller for Information Extraction

The controller of this system receives the observation data acquired by many sensors and processes them with the information integration server. The information integration server analyzes the observation data and identifies the target status. If the controller analyzes the data and determines that the target is in an urgent state, it notifies the preset watcher of the state. Otherwise, if the level of urgency is not high, send observation data and advice to the target person or watcher. The data acquired by the controller is stored in a database on the cloud via the network while ensuring anonymity.

By analyzing sensor data acquired by this system collected on a database using a general rule base, the occurrence of an accident is detected immediately and predicts signs of illness. Besides, reading unusual movements, voices, and atmospheres help to detect changes in the body and mind by noticing minute changes, by accumulating daily life. These functions provide appropriate advice to the watched person based on the analysis results.

Also, if an emergency such as an accident or sudden illness occurs, you will be immediately notified of the appropriate emergency contact. The system also analyzes the data to estimate health hazards. And since people improve their lifestyles based on system suggestions, they reduce the chance of getting sick. The system also analyzes the data to estimate health hazards. The system alerts you to risk of illness based on your estimates and suggests lifestyle improvements when needed. Also, the system observes if they have changed their lifestyle after advice.

C. Monitors for Presentation

The design of a monitor that displays information needs to consider two main objects. One is for the watchers. They may or may not always be watching the monitor. When the person watcher is watching as a job, it is necessary to provide detailed information to the monitor so that the real-time situation of the watching target can always be grasped. If not constantly monitored, it may be better to only provide when a watched person has an emergency or when there is some major change in the person, rather than providing detailed information.

Another thing to consider as a monitor is how to present information to the target audience. The target uses the monitor to understand its condition. Visualizing a condition can help you understand important data and life patterns, even for small changes that you may not notice. By providing this feature, you can expect your target to care about your health. Also, utilizing character devices such as humanoid robots for the monitor interface can be expected to proactively improve lifestyles.

V. System Implements

To realize this system, the monitoring device was implemented. The device consists of one controller and multiple sensors. Raspberry Pi 3B is used as a device to mount the system controller. The controller connects a Grove Base HAT for easy sensor mounting. By using the Grove Base HAT, the controller can connect various Grove sensors.

The controller for this system is running the Raspbian OS on a Linux distribution. The controller has a module that displays the acquired data on the console and a module that writes the data to a file. Also, a module was created in the controller for target state analysis based on the data obtained from the sensor. The module has a crisis detection routine and an advice routine. We also created an interface module for presenting the target status and advice to the watcher and the target itself by controlling the robot away from the controller.

On the sensor side, a millimeter-wave sensor and a multichannel gas sensor were used for the sensor implementation. The millimeter-wave sensor is one of the remote sensing devices that use millimeter-wave radio waves. The sensor emits a continuously modulated radio wave. Then, the sensor captures the reflected wave. As a result, the sensor indicates the distance, speed, and angle of the object. Fig. 4 shows a plot of an object observed using a millimeter-wave sensor.

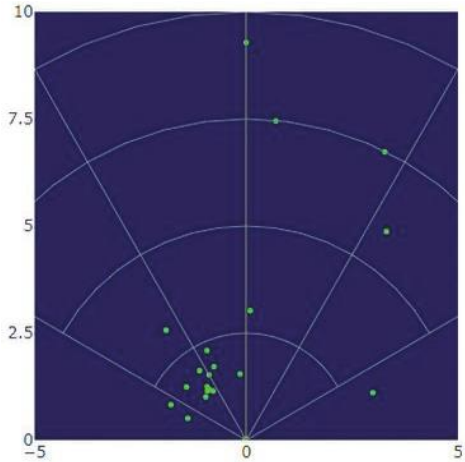

Fig. 4. Object detection display by millimeter wave sensor

The multichannel gas sensor measures the concentration of VOC (Volatile Organic Compounds) in the air. The sensor used this time can measure eight of these gases (CO, NO_2, H_2, NH_3, CH_4, C_2H_6OH, C_3H_8, C_4H_{10}). Not only are these defects contained in the atmosphere, but some things are included in the breath of a person, and the amount contained in the breath changes depending on the life and physical condition of the person. This system classifies human behavior by integrating the acquired data of these two sensors. It has been the watched person of much research to elucidate safe levels

of indoor VOC concentrations [17]. The system uses the values to determine crisis detection.

Therefore, the value of the gas sensor fluctuates when a person is nearby. Table I shows the change before and after when the gas sensor is blown at a close distance. If they breathe directly on the sensor, it will fluctuate greatly. For this reason, in the processing used in this system, the watched person changes the threshold value depending on the positional relationship with the gas sensor. If the watched person is in a very different position from the gas sensor, even if the value of the gas sensor changes significantly, it is acceptable. As a result, it becomes possible to grasp the situation that cannot be judged only by the gas sensor.

TABLE I: CHANGES WHEN BREATHING INTO THE SENSOR

VOC	Before (PPM)	After (PPM)	After/Before
NH_3	0.31	0.34	1.10
CO	0.34	2.26	6.65
NO_2	0.63	0.60	0.95
C_3H_8	177.56	196.59	1.11
C_4H_{10}	147.85	157.79	1.07
CH_4	0.05	54.73	1094.60
H_2	0.01	0.21	21.00
C_2H_5OH	0.01	0.27	27.00

On the monitor side, the user can confirm the information by accessing the web application running on the Raspberry Pi 3 web server using the HTTP protocol. The communication robot installed on the observer side is operated from the controller side using the MQTT (Message Queue Telemetry Transport) protocol. MQTT is a relatively lightweight network data delivery protocol that uses Publisher-Subscriber type delivery over TCP/IP. By adopting this, the system can distribute sensor data with a smaller amount of data communication as compared with general data communication protocols on the Internet.

VI. PRELIMINARY EXPERIMENTS

A prototype system had tested the effect of observing the subject using multiple contactless sensors integrated and used. After that, the effect of using a contactless sensor was tested by using the prototype. In conducting these experiments, three types of sensor patterns were prepared that the system installed in the room to observe the target.

The three sensor patterns used in this experiment were set. The first is when using only millimeter-wave sensors, the second is when using only gas sensors, and the third is when using both millimeter-wave and gas sensors. During this experiment, the system will continue to use sensors to send observations of the room containing the target to the controller. The controller confirms whether or not the presence or health condition of the monitoring target person can be identified by performing real-time analysis using the set three patterns of data.

During the experiment, a millimeter-wave sensor and a gas sensor were installed in a laboratory that assumed a living room alone. Those sensors were installed in the same position. The millimeter-wave sensor measures the movement of the watched person and the positional relationship with the gas sensor. The gas sensor measures the indoor air environment. During the experiment, the person stayed near the gas sensor or breathed on the gas sensor.

As a result of the experiment, the gas concentration threshold value for generating a warning was changed according to the change in the gas sensor data and the positional relationship between the watched person and the gas as compared with the case where each sensor was used alone. By changing this, it was possible to suppress the generation of excessive alerts.

VII. CONCLUSION

In this paper, a new method was proposed to know the health condition of the lived alone. The model employs an algorithm that measures the degree of urgency based on information obtained from sensors. It changes the method of reporting and advice accordingly. A system that implements the design installs multiple contactless sensors in the house and acquires live alone health data.

The prototype system was implemented and tested, and it was confirmed that the models and algorithms worked. The system has millimeter-wave radar and multiple gas sensors. The system can classify the situation of living alone by using and integrating the information obtained from them.

This experiment uncovered a problem with monitoring systems that use sensor integration. One of them is the privacy issue of the watched person. The system receives detailed changes in people and rooms through sensors, thereby detecting the condition of the person. The system reports alerts and advice based on the results. Therefore, the watched person must choose beforehand whether the system will notify the watcher of such information, based on its benefits and risks.

As a case of using this system, if the observed data behaves as if there is no problem with the person's intent, the false alarm rate may increase, and the werewolf effect may occur. Therefore, when the person watcher in this system receives an alert, the person watcher the system needs the means to verify the safety of the person. In that case, whether the system will perform this verification or humans will have to consider. For human execution, it is desirable to provide an interface that allows the person to watch the system to confirm safety by communicating with the target.

CONFLICT OF INTEREST

I declare no conflict of interest.

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