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A Study on the Design of Real-Time Monitoring System Using IoT Sensor in Respirator

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Abstract

A lot of research has been conducted on a system that collects and observes patients' health information in real time using Internet of Things (IoT) technology, and cares for and supports patients based on this. However, most studies have focused on underlying diseases such as diabetes or cardiovascular disease, and research on IoT systems to cope with respiratory infectious diseases such as COVID-19 is still insufficient. In a COVID-19 situation, the purpose of using an IoT respirator may vary depending on the user. In this paper, we design a system that can adequately cope with respiratory infectious diseases such as COVID-19 by applying IoT technology to respiratory protection. We categorize IoT respirator wearers into patients, medical staff, and self-quarantine persons, and define the purpose and use case of the IoT respirator system according to each classification. The proposed IoT respirator system was designed to achieve each purpose. We developed a prototype system consisting of a smart sensor, a communication module, and a non-motorized hooded respirator to show that the proposed IoT respirator system works.

Keywords: *COVID-19, IoT, Smart Sensor, Non-Motorized Hooded Respirator, Prototype System*

1. Introduction

The world is in chaos due to the highly contagious and fatality rate of COVID-19. In particular, the global market for respirators and artificial oxygen respirators is rapidly increasing to protect against respiratory viral infections. Respirators are divided into health masks to protect the health of the public from bad air, surgical masks for medical purposes, artificial respirators for patients with difficulty in self-breathing, and industrial respirators to protect industrial workers. However, there are not many respiratory protection products specialized for respiratory viruses. Due to the COVID-19 outbreak, hospital medical staff initially wore a Level D - health mask according to the standards of the National Institute of Occupational Safety and Health (NIOSH), but recently replaced with a Level A - Powered Air Purifying Respirator (PAPR).

A number of studies have been conducted on a system that supports patients based on collecting and observing patient health information in real time using various biosensors and Internet of Things (IoT) technology. However, research on the development of IoT systems suitable for the COVID-19 situation is still

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insufficient.

In a COVID-19 situation, the purpose of using an IoT respirator may vary depending on the user. First, when a patient with COVID-19 infection wears an IoT respirator, it is important to check that the mask is tightly attached to the face so that the virus does not leak to the outside. In addition, a function of measuring the severity of the disease according to the patient's condition information is required. Second, in the case of COVID-19-related medical staffs, it is necessary to maintain close contact with the face to prevent the influx of virus into the respirator and to check the fatigue of the respirator wearer. Thirdly, in the case of COVID-19 self-quarantine persons, it is important to monitor whether or not to maintain close contact with the face to prevent virus outflow outside of the respirator and to detect COVID-19 symptoms based on the wearer's physiological information. Unlike the existing IoT healthcare systems, the IoT respirator system for COVID-19 has its main function different depending on the wearer's situation, so it is necessary to define and design the system for each case.

In the present paper, we define the purpose of various wearers in COVID-19 situations and design an IoT respirator system that can support each purpose. Using smart sensors and IoT technology, a respirator, a simple tool that protects the wearer's respiratory system, is made into an active system that can detect the wearer's condition and respond accordingly. The remainder of the paper is organized as follows.

In Section 2, related works are reviewed. Section 3 describes the respirator, smart sensor, and communication module that make up the IoT respirator system. It also describes the architecture of the IoT respirator system and explains what each component does. In Section 4, we define the purpose of the IoT respirator system that varies depending on the wearer, and describe the use case for each purpose. Section 5 describes a prototype tool developed to demonstrate the operation of the proposed IoT respirator system. Finally, Section 6 summarizes and concludes this paper.

2. Related Work

Many studies have been conducted that introduced IoT technology into the healthcare field. IoT solutions for healthcare started from a simple structure that collects and visualizes biometric information. Currently, it is developing into a system that collects biometric information from smart sensors, analyzes it, and makes decisions using artificial intelligence [1-3].

H. Fouad et al. [4] developed an IoT sensor-based health information system to support patients, and applied an iterative-golden section optimized deep belief neural network (IGDBN) as a model for patient condition analysis. It was suggested that the patient analysis system based on IGDBN shows better accuracy and lower error rate compared to other artificial intelligence models.

J. Granados et al. [5] presented a practical IoT platform for monitoring and classification of the 12-lead electrocardiography (ECG). They designed a Bluetooth 5 multichannel ECG monitoring device which connects to a cloud service via smartphone gateway using the generic attribute profile (GATT) protocol and enabled notifications.

P.M. Kumar et al. [6] propose a new Cloud and IoT based mobile health care application for monitoring and diagnosing the serious diseases. They developed a new classification algorithm called Fuzzy Rule based Neural Classifier to diagnose diabetes and to identify the severity of symptoms.

A. Subasi et al. [7] developed a robust and precise human activity recognition model based on IoT technology. The proposed model utilizes a data set containing a record of body movements and vital signs for 10 volunteers. They performed 12 physical activities for human activity recognition purposes. The proposed system showed excellent performance and very effective with an accuracy of 99.89%.

L. Liu et al. [8] proposed a new method to identify Alzheimer's disease (AD) using spectrogram features extracted from audio data instead of medical images. They collected voice data from 23 elderly people using IoT devices, and applied machine learning technology to analyze this data. The final experimental results showed that the LogisticRegressionCV model achieved the best performance among several tested machine learning models, and it was possible to identify AD using spectrogram features in the voice.

In most cases, existing studies aim to measure physiological information remotely for patients with underlying diseases such as diabetes or cardiovascular disease, and to properly manage patients. In contrast, this study is differentiated in that it supports rapid response to infection situations by reinforcing the function of respiratory protective equipment of patients or medical staff using IoT technology in the COVID-19 situation.

3. Design of IoT Respirator System

3.1 Respirator

Standards for respirators differ from country to country. In the United States, the Institute of Industrial Safety and Health (NIOSH) classifies masks into N95, R95, P95, N99, R99, P99, N100, R100, and P100 according to the filter's purification capacity. In Korea, it is classified into KF-AD, KF80, KF94, and KF99 according to the Pharmaceutical Affairs Act. In Europe, according to the EN 149 standard, health masks are classified into FFP1, FFP2, and FFP3 based on filtering performance.

Personal protective equipment (PPE) that protects the body, including the respiratory system, is classified into Level-A, B, C, and D according to the standards set by NIOSH [9].

Level-D is the lowest risk protection level, it requires a health mask and goggles or face shield, and safety shoes/boots. Level-A protection should be worn when the highest level of respiratory, skin, eye and mucous membrane protection is needed. It includes positive-pressure supplied air respirator, fully encapsulating chemical protective suit, and chemical resistant gloves/ boots. According to the research results of Alexis Tabah et al. [10], the ratio of N95/FFP2 masks used by medical staff in COVID-19 situation was the highest at 57%, followed by N99/FFP3 masks at 25%. The ratio of using surgical mask was 11%, and the ratio of using PAPR, Level-A PPE with the highest defense power, was 7%.

In order to deal with highly contagious respiratory infectious diseases such as COVID-19, the use of PAPR is desirable, but the practical use is limited. PAPR is a disposable device that cannot be cleaned even though it is expensive, so it can only be used for a few hours, making it difficult to use as an equipment to cope with the rapidly increasing number of COVID-19 patients around the world. To replace the expensive and disposable PAPR, research and development projects are underway in research institutes around the world using a full-face snorkeling mask [11].

3.2 Smart Sensor and Communication Module

The IoT respirator is equipped with sensors that measure physiological information and a communication module that can transmit the measured data to the server in real time. To measure the wearer's condition, the sensor must be able to measure information such as temperature, humidity, air quality, and air pressure. If necessary, sensors that measure heart rate or oxygen saturation may be added.

By analyzing the information measured by these sensors, it is possible to confirm whether the wearer has fever and whether there is a problem with breathing. In addition, by analyzing the change in the air pressure value, it is possible to check whether there is a possibility of inflow or outflow of a virus because the mask does not adhere to the wearer's face.

According to the overall architecture and usage scenario of the IoT respirator system, the specific communication technology of the communication module attached to the respirator is selected.

If there is a terminal such as a smartphone that can receive and process data measured by sensors in a short distance of an IoT respirator, for the communication module attached to the IoT respirator, Wireless Local Area Network (WLAN) technologies such as Bluetooth Low Energy (BLE), ZigBee, and WI-FI are suitable. If there is a possibility that the IoT respirator wearer cannot carry a smartphone, the respirator communication module should be equipped with a Low Power Wide Area Network (LPWAN) function such as LTE-M, NB-IoT, and LoRa.

In this study, in developing a prototype for the IoT respirator system, BLE was selected as the main communication technology of the communication module attached to the IoT respirator under the assumption that the wearer carries a smartphone.

3.3 Architecture of IoT Respirator System

The overall architecture diagram of the IoT respirator system is shown in Figure 1. A sensor attached to the mask collects the wearer's status information in real time. This information is transmitted to the smartphone app carried by the mask wearer through the communication module. The smartphone app analyzes the wearer's state information in real time and immediately informs the wearer when the data value exceeds a specific threshold. The wearer's status information is periodically transmitted to the data server by the smartphone app.

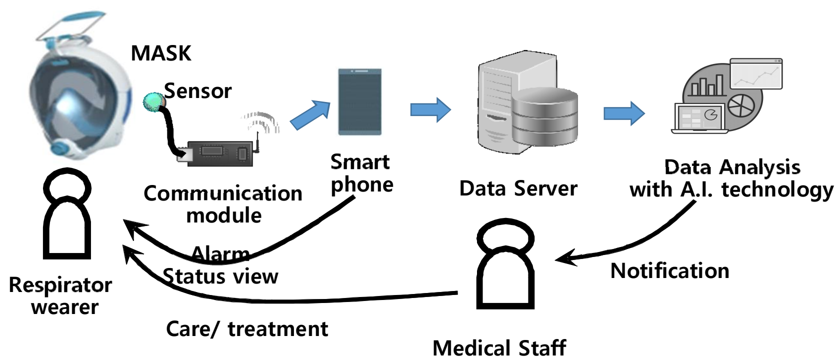

Figure 1. Overall architecture of IoT respirator system

The wearer's state information stored in the data server is analyzed by artificial intelligence technology such as machine learning. According to the analyzed result, if the wearer needs medical treatment, the result is notified to the medical staff.

4. System Purpose and Use Case

The purpose of the IoT respirator system depends on who the wearer is. First, it is necessary for medical staff to wear IoT respirators to protect themselves from respiratory viruses. Second, it is necessary for patients with respiratory infections to wear respirators to prevent transmission to others. Lastly, it is necessary for people who need self-quarantine for a certain period of time to wear IoT respirators because they are classified as close contacts of patients with respiratory infections. For each wearer classification, the main purposes and use cases of the IoT respirator system are as follows.

4.1 Medical Staff

Respiratory protection is required for medical staff because they are in direct contact with patients with respiratory infections.

The IoT respirator system protects the medical staff's breath from external viruses and at the same time detects changes in air pressure within the respirator to check whether the respirator is properly attached. If the respirator does not fit properly or if there is a temporary gap, the IoT respirator system must notify the wearer immediately so that it can be corrected. Next, the wearer's fatigue level can be measured through the breathing frequency, air quality and temperature in the mask, and wearing time, and if fatigue exceeds a certain level, it should be managed appropriately. Finally, it is possible to determine whether the wearer has symptoms of respiratory infections by analyzing temperature, respiratory frequency and intensity, cough, and air quality. The main purposes of the IoT respirator system for medical staff are as follows.

- Checking if the mask fits well on the face
- Measuring and managing fatigue of respirator wearers
- Detecting symptoms of respiratory infections

4.2 Patients with Respiratory Infections

Respiratory protection must be worn by patients with respiratory infections when moving to another location or in a common space where other people can stay. At this time, the respirator must be equipped with a function to sterilize the wearer's exhaled air, filter it, and discharge it to the outside. When wearing a respirator equipped with such an exhalation filter, the burden on the patient himself and the medical staff taking care of the patient can be greatly reduced. In addition, if the number of patients suddenly increases, the problem of lack of negative pressure isolation ward may occur, and this respiratory protection could alleviate some of this problem.

When a patient wears an IoT respirator, it guarantees a tight fit between the respirator and the face, and it is possible to continuously check the severity of the disease by analyzing fever or breathing patterns. If, initially, asymptomatic or mild patients show symptoms of a severe illness after a certain period of time, the IoT respirator system notifies the medical staff to provide appropriate medical treatment. The main purposes of the IoT respirator system for patients are as follows.

- Checking if the mask fits well on the face
- Measuring and managing the severity of the wearer's infectious disease

4.3 Self-Quarantine Person

In Korea, close contacts of COVID-19 patients must self- quarantine at home or in a self-quarantine facility for two weeks. When a self-quarantine person has to live in a house with his family due to personal circumstances, it is desirable to protect the family from infectious diseases by wearing a respirator with an exhalation filter attached.

Self-quarantine persons should report physiological symptoms to the medical staff in charge periodically. When a self-quarantine person wears an IoT respirator, it guarantees a tight fit between the respirator and the face, and periodically automatically reports the wearer's physiological symptoms to the medical staff in charge.

In addition, it analyzes whether symptoms of an infectious disease have occurred, and if it is suspected that the wearer is infected, it is immediately notified to the responsible medical staff so that medical treatment can be taken.

- Checking if the mask fits well on the face
- Automatically report the wearer's physiological symptoms periodically
- Detecting symptoms of respiratory infections

5. Development of Prototype System

In this study, a prototype of an IoT respirator system was developed using a non-motorized hooded respirator product developed by a startup company to replace expensive and disposable PAPR. Bosch Sensortec BME680 was used as a sensor attached to the respirator. The BME680 combines a gas sensor with barometric pressure, humidity and ambient air temperature sensing [12].

We selected the ESP32 module developed by Espressif Systems as the communication module for the IoT respirator system. ESP32 supports BLE and WI-FI communication functions. The esp32 module is small in size and operates with low power, so it can be mounted on a respirator and operated for a long time. It is also advantageous for mass production because of its low price [13]. The appearance of these products is shown in Figure 2.

Figure 2. Devices used to develop a prototype system

The developed prototype system collects temperature, humidity, air pressure change, and gas information in the wearer's mask from sensors mounted on the respirator, and transmits it to a smartphone app. The smartphone app notifies the wearer when the measured physiological information value exceeds the threshold value. In addition, the smartphone app periodically transmits the wearer's physiological information to the data server. Figure 3 shows the graph of the data measured by the sensor mounted in the IoT respirator on a smartphone. The graph on the left of Figure 3 shows the temperature inside the mask, and the graph on the right shows the change in air pressure inside the mask.

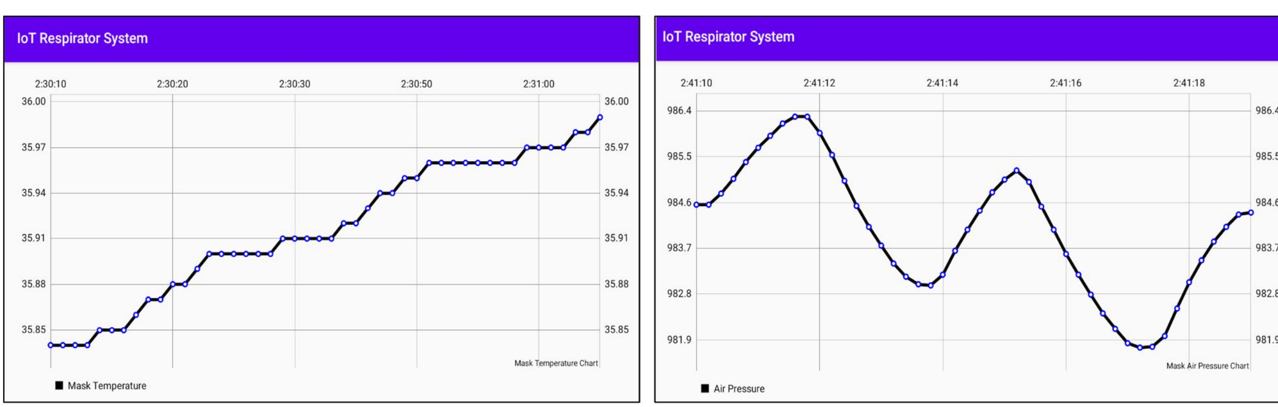

Figure 3. Graph of the data measured by the sensor

Since the wearer's physiological information has not been sufficiently accumulated, the function of analyzing information with machine learning technology has not been implemented. In particular, it is difficult to use patient physiological information as research data according to medical law. Therefore, we plan to first apply the IoT respirator system to medical staff, and build a machine learning model using the data obtained through it.

6. Conclusion

In this paper, we designed an IoT respirator system to cope with COVID-19 infectious diseases. The purpose of the IoT respirator may vary depending on the wearer - medical staff, patients, and self-quarantine persons. We defined the purpose of the IoT respirator system according to each wearer's classification and designed a system to support it.

The IoT respirator collects the wearer's physiological information and transmits this information to the data server through a smartphone app. The wearer can check his or her health status using a smartphone app. Also, if the mask is not properly covered on the face, the smartphone app alerts the wearer with a beep so that the wearer can correct it. The use of the proposed IoT respirator system has the advantage of being able to centrally manage the wearer's physiological information, saving manpower, and being able to respond quickly in case of emergency.

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