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Control Design Applicable to a Helmet Type Full-face Mask

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Abstract. Since the worldwide outbreak of COVID-19, the use of face masks has become ubiquitous in most countries, and awareness of using masks has also increased significantly. In our research, a lightweight helmet type full-face mask has been developed. In this development, the precise control has been designed to control the air flow and pressure inside the mask for suppling fresh air and keeping the inside pressure slightly higher than outside. The CO_2 alarming system has been introduced for preventing the high concentration of carbon dioxide inside the mask. The experimental setup has been constructed based on an Arduino digital controller and experiments has been carried out. The system performance is successfully verified.

1. Introduction

Coronavirus disease 2019 (COVID-19) has been declared a pandemic, and globally more than 28 million confirmed cases of which includes over 900,000 deaths have been reported by the World Health Organization (WHO), as of early September [1]. The cumulative incidence of the pathogenic virus (SARS-CoV-2) has increased rapidly and has affected 196 countries and regions, of which the United States, Spain, Italy, the United Kingdom and France are the most affected [2]. The outbreak of COVID-19 in Japan started from the mass infection incident on a cruise ship called the Diamond Princess [3]. Since March, the number of newly confirmed cases has increased significantly every day, and the situation has improved significantly in early May. However, there was a second outbreak since July, and it was more severe than the previous one [4]. It is commonly considered that COVID-19 is still an unclear infectious disease, which means it is hard to know or predict when it will end [5].

Since the worldwide outbreak of COVID-19, the use of face masks has become ubiquitous in most countries, and awareness of using masks has also increased significantly. Despite the fact that people in Asian countries, especially in Japan, have a relatively higher acceptance of using face masks as hygienic practice rather than only symptomatic individuals and those working in medical institutions are recommended to use face masks, the effectiveness of wearing a face mask to protect yourself from viruses is considered to be limited, not to mention the dyspnea caused by long-term wearing of face masks [6,7]. It is as well believed that, once epidemics begin, substantially increased use of face masks exacerbates the supply shortage of face masks. In such a situation, the supply of front-line medical professionals will be threatened, and people's economic and social life will be severely affected, such as the economic recession under the lock-down policy. Makeshift alternatives or repeated usage of disposable masks are opted in some regions, while improper use of disposable masks could increase the risk of infection instead [8].

Regarding the issues above, we have invented a lightweight full-face helmet-type mask that completely shields the invasion of viruses from the outside (and almost completely shields the discharge of viruses) [9]. Our invented full-face mask has simultaneously achieved the following four features of 1) complete screening of viruses, 2) lightweight body, 3) easy breathing and 4) inexpensive manufacturing cost, in a high dimension. At the same time the precise control has been introduced into the system to control the flow and pressure inside the mask. In this paper, the control design applicable to the full-face mask has been described. Also, the CO_2 sensor alarming system is applied for preventing the high concentration of carbon dioxide inside the mask. People who wear such masks, like antibody carriers, cannot be infected with the virus themselves, nor can they spread the virus to others. The popularization of this mask will greatly reduce the dilemma caused by the virus epidemic.

2. Configuration of full-face mask

The proposed full-face mask can be divided into two parts namely helmet part and backpack part. Fig. 1 shows the helmet part of the full-face mask and Fig. 2 shows the augmented mechanism of air supply and purified air system.

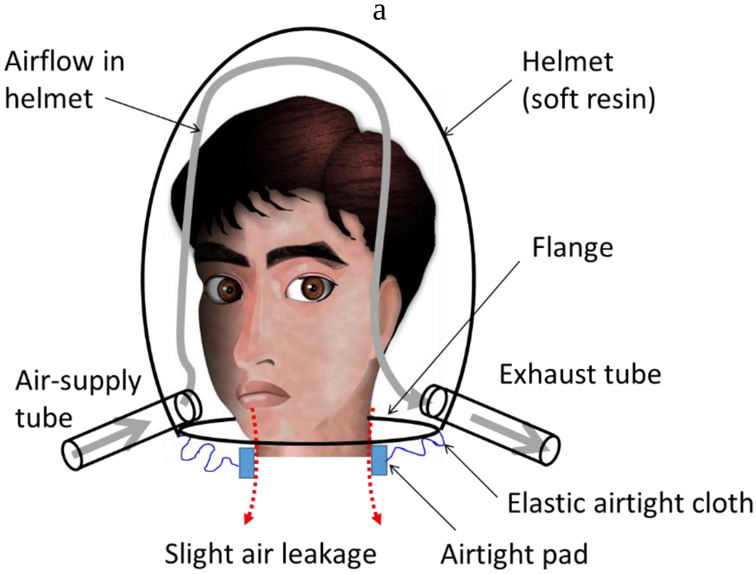

Fig. 1. Airtight helmet part.

As shown in Fig. 1, the helmet part includes the helmet which is made by soft resin materials, one air supply tube for providing the airflow inside the helmet to ensure the human breath, one exhaust tube for the air flowing out to prevent high concentration of carbon dioxide. And based on the mechanism design for the air supply, this helmet type full-face mask has the following three features.

(1) Constant air flow with fresh air: This mask includes one supply fan to take in the fresh air, and the exhaust fan to take out the breath air inside the helmet, thus, by controlling the air supply fan and exhaust fan can control the air flow inside the helmet. As a result, fresh air can be breathed without adding extra load to the lungs.

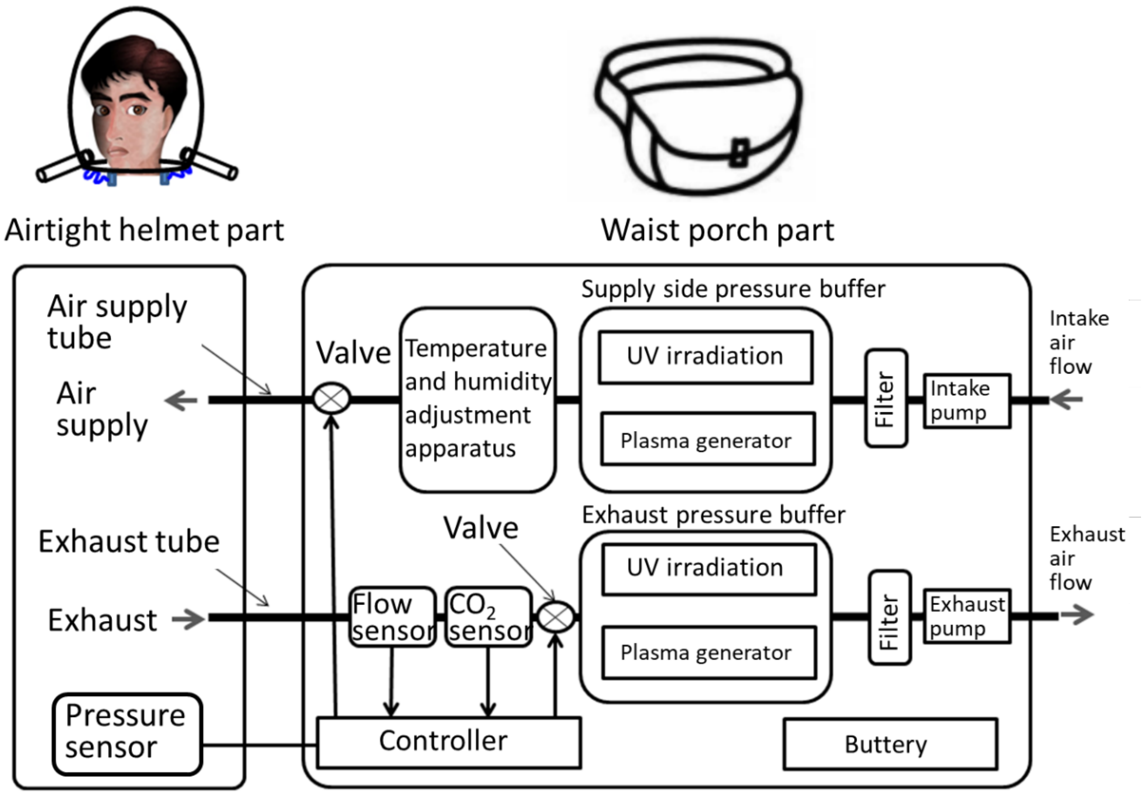

Fig. 2. Mechanism of air supply and purified air system.

(2) Positive pressure inside: For the human breath, it is better to control the inside pressure be a slight positive pressure. It is possible to completely block the entry of outside air from the seal part of the neck. In addition, the helmet dome can be made of a lightweight transparent resin material by keeping the internal pressure high to some extent. Invasion of virus can be blocked 100%. The virus emission depends on the air tightness of the neck seal, but it can be suppressed at a high level.

(3) High performance filter: This mask has inserted a high-performance filter with extremely large flow resistance by forced air supply and exhaust by a pump, pressure buffer, and electromagnetic control valve housed in a backpack. It is also possible to equip the air supply side and the exhaust side with virus killing devices (such as: UV irradiator, plasma cluster generator, etc.).

3. Control method of the proposed full-face mask

To realize the features mentioned above, the closed loop control system needs to be introduced to ensure the air flow and keep the positive pressure inside the helmet. In our proposed full-face mask, the air supply pump and exhaust pump are driven by the PWM duty of the driving circuit.

Fig. 3 shows a block diagram of the basic configuration of the control system related to the helmet type mask which completely shields viruses. The flow rate and pressure in the helmet are measured by a flow sensor and a pressure sensor. Feedback control is performed by two fans for air supply and exhaust. As a result, the pressure and flow rate inside the helmet are controlled at high response and with high accuracy.

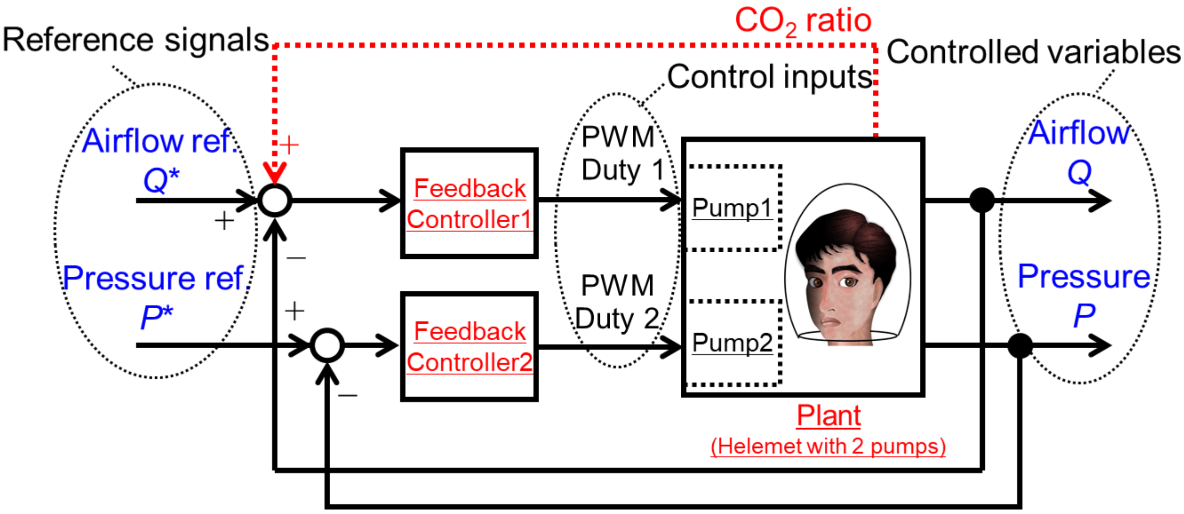

Fig. 3. Block diagram of the control system applied to the full-face mask.

The rotation speed of the exhaust side fan is controlled so that the output of the flow sensor installed in front of the exhaust side pressure buffer quickly follows the reference value. Similarly, the rotation speed of the air supply side fan is controlled so that the pressure in the helmet measured by the pressure sensor follows the reference value.

Here, the flow rate is controlled as a sufficiently large value (40 L/min), considering that human respiration is about 10 L/min. Its responsiveness is fast enough within 1 s. In addition, the pressure inside the helmet is set to a value slightly higher than the external atmospheric pressure (fine positive pressure: +20 Pa, about 0.02% of 1 atmospheric pressure) to completely prevent the entry of outside air. The pressure response is also within 1 s, which is a sufficiently quick response. Due to the forced intake and exhaust of the two fans, a mask filter and a thick filter can be used on the inside (helmet side) without preventing the flow.

In addition, a CO_2 sensor is installed and monitored in the helmet, and the carbon dioxide concentration of the situation inside the helmet is constantly monitored. When it exceeds a certain value (set to 2000ppm, the maximum value of dirty air), the flow rate is increased and an alarm is set to sound.

The prototype model has two fans installed for clarity, but this function can also be realized with one fan and one valve. In addition, the sensor measurement, fan, and control unit are all driven by a single battery (12V lithium-ion type). Also, for the sake of ease of recognition in the demonstration, a large-sized fan that produces sound is used, so a backpack of this size is used. However, considering the miniaturization, it can be made into a volleyball size, a large lunch box size, or a helmet-built-in type, and it is fully portable.

As a verification of each feedback control effect, for example, when the tube on the exhaust side is pinched and the flow rate is reduced, the rotation speed of the exhaust side fan increases in order to increase the flow rate. If the cover under the helmet is pushed back and the internal pressure is increased, the internal pressure tries to decrease to the set value, and the rotation speed of the air supply side fan decreases. Furthermore, if you repeat quick breathing in the helmet and increase the carbon dioxide concentration, the CO_2 sensor will sound an alarm.

4. Construction of full-face mask

Based on the formal analysis and design, the setup has been built up based on the Arduino digital controller, the two pumps are driven by MOSFET circuit as shown in Fig. 4.

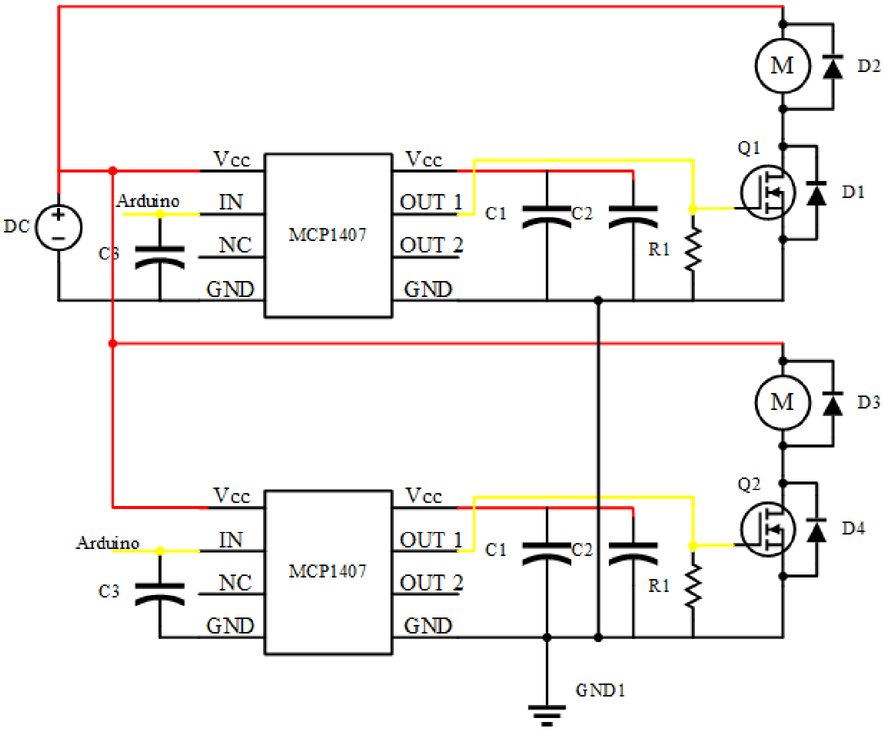

Fig. 4. Pump driving circuit.

By using this driving circuit, we have constructed the full-face mask. The system configuration of the developed mask is shown in Fig. 5 while the constructed mask is shown in Fig. 6.

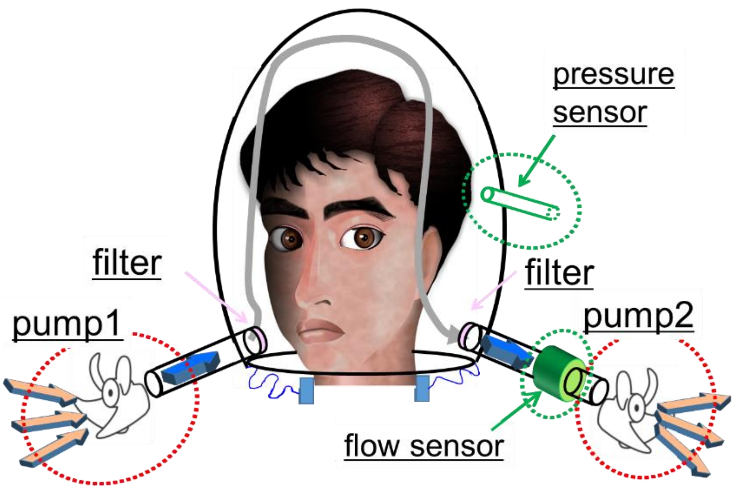

Fig. 5. System configuration.

Fig. 6. Developed full-face mask.

The components information of the experimental setup is shown in Table 1. The experiments have been carried out to evaluate the control performance, the experimental results are shown in Table 2.

From Table 2, both the response time of pressure difference and air supply flow are 0.5 s, smaller than 1s. It can be concluded that the system satisfies the required condition of the mask.

Table. 1. System parameters

Parameters	Value
Power supply	12V DC battery
Controller	Arduino Due
MOSFET	IPP072N10N
MOS driver	MCP1407
Flow sensor	SFM3000
Pressure sensor	SDP8xx
CO_2 sensor	MH-Z14
PWM frequency	1kHz

Table. 2. Control system parameters

Parameters	Value
Flow reference	40 L/min
Pressure difference reference	60 Pa
CO_2 alarm reference	3000 ppm
Flow response time	0.5 s
Pressure difference response time	0.5 s

3. Conclusion

In this paper, a helmet type full-face mask has been invented. The invented mask can completely shield the invasion of viruses from the outside (and almost completely shields the discharge of viruses). Four features of 1). complete screening of viruses, 2). lightweight body, 3). easy breathing and 4). inexpensive manufacturing cost have been achieved in a high dimension. The precise control has been introduced into the system to control the flow and pressure inside the mask. Also, the CO_2 sensor alarming system is applied for preventing the high concentration of carbon dioxide inside the mask. The experimental setup has been built based on the Arduino control center and experiments has been carried out to evaluate the control efficiency. The invented full-face mask has been successfully verified.

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