Journal of Mechanical and Electrical Intelligent System (JMEIS)

Personal Respiratory Air Purification Device (Helmet-type): Distancing-Free Mask (Prototype No.5)

Yusaku Fujii[1,a,*] and Akihiro Takita[1,b]

[1]School of Science and Technology, Gunma University, Kiryu 376-8515, Japan

*Corresponding author

[a]<fujii@gunma-u.ac.jp>, [b]<takita@gunma-u.ac.jp>

Keywords: Herd immunity, lockdown, social distancing, COVID-19, SARS-CoV-2, droplet, aerosol

Abstract. The Distancing-Free Mask, which is an inexpensive and high-performance helmet-type respiratory air purification device, is improved. Its wearers can go out freely even when the lockdown is needed, since they cannot be infected from others and cannot infect others. We propose a new social system, in which the lockdown is not needed, by means of spreading the devices throughout the society.

1. Introduction

The world is in an intermittent lockdown state due to COVID-19 [1,2,3]. 'Herd immunity' is normally obtained either through vaccination or immunity developed through previous infection. WHO supports achieving 'herd immunity' through vaccination, not by allowing COVID-19 to spread through any segment of the population, as this would result in unnecessary cases and deaths [4].

Lockdown is a measure to uniformly reduce interpersonal contact in a situation where it is unknown who is infected in order to stop the spread of infection. Among the infection routes of COVID-19, contact infection and oral infection are relatively easy to prevent by enforcing hand washing and food hygiene management. Droplet infection and airborne infection are the main infection routes that are difficult to prevent [5]. If a personal device that completely blocks droplets and aerosols is developed, it is considered that the person using the device can go out freely even during lockdown.

The authors propose an alternative engineering way to achieve 'pseudo herd immunity' through the mass spread of the almost-perfect mask. This proposal is based on the following 3 simple ideas/hypothesis.

[a] Mass production of helmet-type masks, which shield viruses 100%, is easy with the modern technology.

[b] If every person wears the helmet-type mask all the time, anyone cannot be newly infected. And all the airborne infectious diseases, including COVID-19, will be shut down promptly.

[c] Considered in the same way as herd immunity, the mask wearing rate, which is required to converge the infection, is not necessarily 100%.

The authors have developed a series of the personal respiratory air purification device “Distancing-Free Mask”. The latest prototype, which is the improved from the previous ones [6,7] and based on the inventions made by the authors [8,9], is described in this paper.

2. Distancing-Free Mask (Prototype No.5)

Figure 1 shows a schematic diagram of the prototype of the helmet-type mask. Figure 2 shows a photograph of the helmet-type mask. The helmet-type mask has an airtight structure. Based on a light-

work helmet, a transparent vinyl chloride screen and a vinyl skirt are attached to it to create an airtight structure. The neck seal is constructed by embedding two rubber cords in the vinyl skirt.

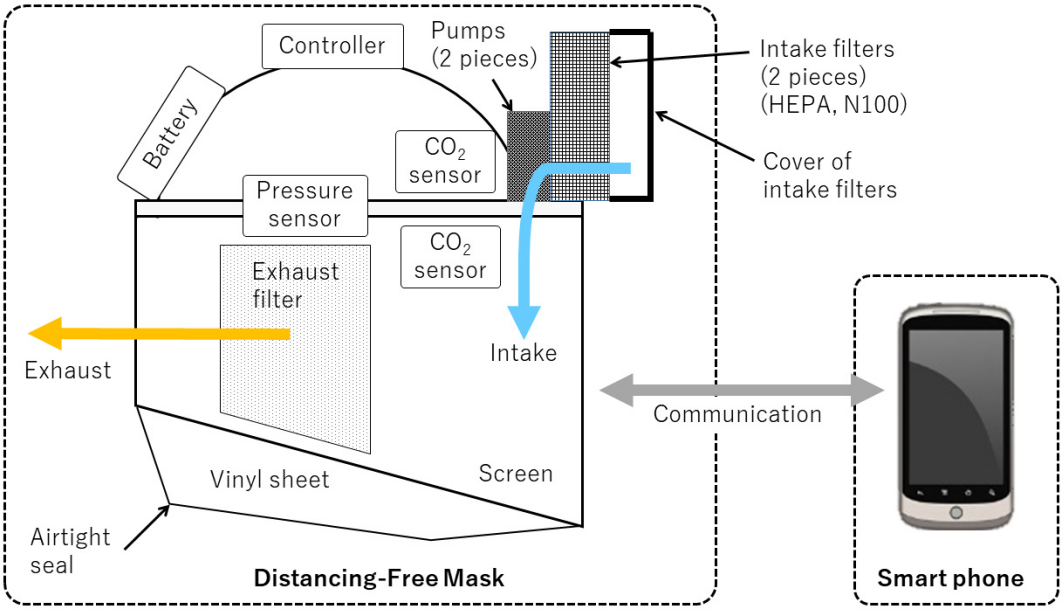

Fig. 1. Schematic diagram of the helmet-type mask

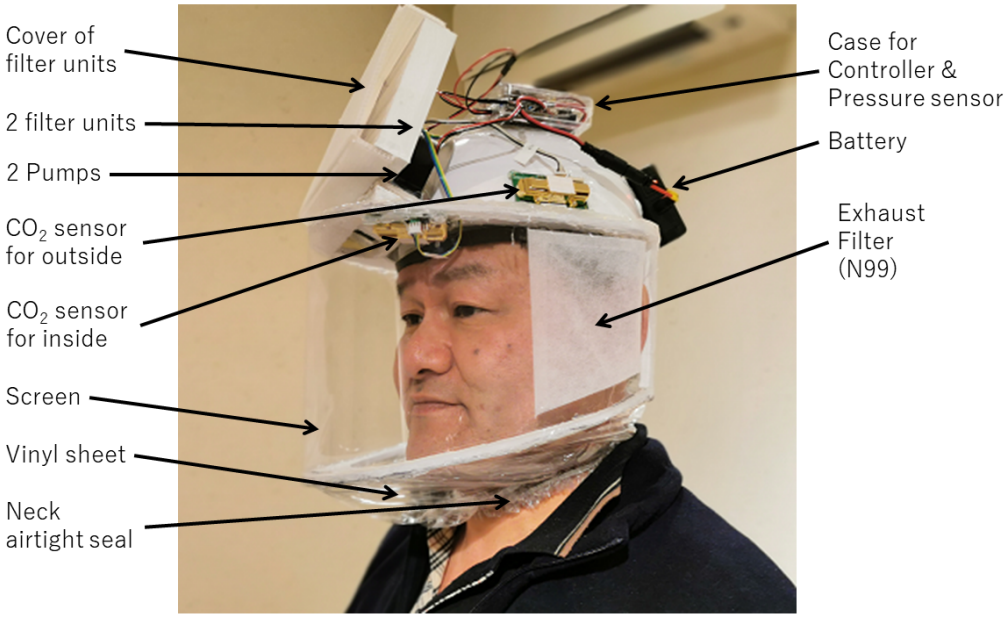

Fig. 2. Photograph of the helmet-type mask

As for the air supply, the outside air filtered by the two filter units attached to each of the two pumps (model: PABD16025BH, manufacturer: Wideworks Co. Ltd.) is supplied to the inside of the helmet. A non-woven filter is folded into the filter unit in a bellows shape. The non-woven filter removes at least 99.97% of particles of the air down to at least 0.3 μm in size. With two filter units, the total area is approximately 1,200 cm^2. It is estimated that there is no intrusion of outside air through the possible gaps around the neck seal due to the internal pressure.

As for the exhaust, the air inside the helmet is naturally exhausted from the non-woven fabric filters attached to both sides of the screen near the both ears of the wearers due to the pressure difference between the inside and outside. The non-woven fabric filter removes at least 99% of particles of the air down to at least 0.1 μm in size. With two filters, the total area is approximately 160 cm^2. Leakage to the outside air through the gap around the neck seal is estimated to be about 5% or less.

Based on the above evaluations, the shielding rate of bioaerosols containing SARS-CoV-2 (particle size of 0.3 μm or more) is estimated to be 99.97% for intake air and 94% for exhaust air.

The carbon dioxide concentrations inside and outside the helmet are measured with two carbon dioxide concentration sensors (model: MH-Z14, manufacturer: Zhengzhou Winsen Electronics Technology Co. Ltd.), respectively. The pressure difference between the inside and outside of the helmet is measured with a differential pressure sensor (model: SDP810-500Pa, manufacturer: Sensirion Co. Ltd.). The flow rate is calculated by an experimentally derived calibration formula as a function of pump output and pressure difference.

The controller (model: ESP32 DevKit, manufacturer: Espressif System Co. Ltd.) controls the pump output as follows.
[1] The pressure reaches the set pressure.
[2] If the carbon dioxide concentration does not meet the condition of [external concentration + 1,000 ppm or less], increase the pump output until it is met.

The controller communicates with the smartphone's dedicated application through Wi-Fi communication. The wearer can observe the operating status and make the setting of the operating parameters on the smartphone.

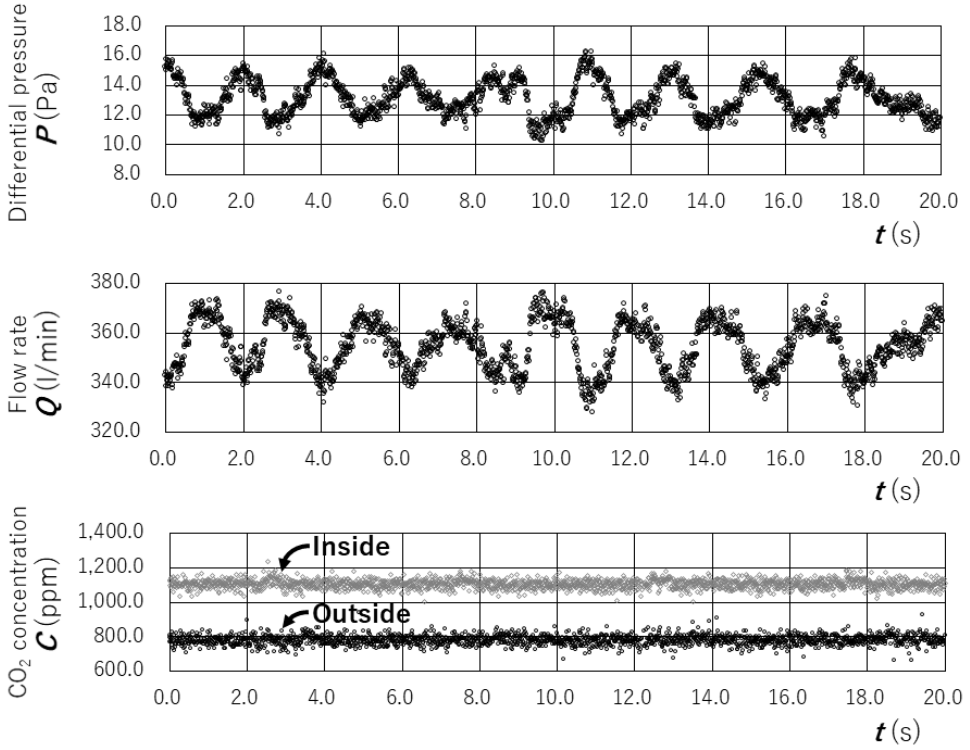

Fig. 3. Time series of control parameters during wearing operation

Figure 3 shows an example of the time series of the differential pressure inside the helmet to the outside, the flow rate, and the carbon dioxide concentration inside and outside the helmet when the wearer wears it. The average value of the differential pressure inside to outside the helmet is 13.1 Pa, the standard deviation is 1.2 Pa, and the set value is 13 Pa. The mean flow rate is 354.6 (l / min) and the standard deviation is 10.1 (l / min). Changes in pressure and flow rate are thought to be caused by breathing of the wearer and by the controller, which controls to make the internal pressure closer to the set value of 13 Pa. The internal pressure rises in the exhaled breath, and the flow rate decreases to suppress it. The internal pressure decreases in the inspiration, and the flow rate increases to suppress it. The mean and standard deviation of the carbon dioxide concentration inside the helmet are 1105.6ppm and 25.6ppm, respectively. The mean and standard deviation of the carbon dioxide concentration outside the helmet are 780.5ppm and 28.2ppm, respectively. In this wearing experiment, it was confirmed that the wearer could talk with the surrounding people without the help of assistive devices.

The dimensions of the prototype are approximately 20 cm (width) x 28 cm (depth) x 36 cm (height). The mass is approximately 769g (including the attached battery 176g). The maximum supply air flow rate is approximately 410 l / min at 15 Pa. The continuous drive time is approximately 4 hours with the normal battery and additional approximately 14 hours with spare battery (379 g). The total cost of parts for making the prototype is approximately 210 USD. If mass-produced, the selling price is expected to be approximately 90 USD.

3. Discussions

The authors believe that the comfort, convenience, functionality and design of the helmet-type masks can be significantly improved if this proposed concept is accepted by the society.

If everyone in the society has this inexpensive and high-performance helmet-type respiratory air purification device, that means the society has the ability to shutdown the infection spread of any airborne infectious disease immediately and easily. With this emergency shut-off measure, the society can allow the people to lead a normal life to the last minute and try various measures with a sense of security.

People normally prefer to drink “purified water” not “natural water of rivers or lakes”. But, people almost always breathe “natural air around them”. With the advent of very-comfortable and almost-perfect helmet-type masks, many people might prefer to wear the masks. This means the emergence of a society that is extremely resistant against all airborne infectious diseases.

5. Conclusions

The authors believe that this proposal is worth considering as one of the countermeasures against COVID-19. If this proposal is taken by the society, people have the options to stay at home or to go out with the devices, when the lockdown is deemed necessary.

Acknowledgments

The authors thank to Prof. Hashimoto for his technical help in control algorithm. The first author thanks Mr. Keizaburo Fujii for his fruitful suggestions and warm encouragements.

References

[1] WHO coronavirus disease (COVID-19) dashboard.

https://covid19.who.int/

[2] COVID-19 Dashboard by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU), ArcGIS. Johns Hopkins University. https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6

[3] Y. Fujii, "Toward coexistence with the new coronavirus", ***Japanese Journal of Social Safety and Privacy***, Vol.4, No.1, pp.1-5, 2020. (in Japanese) http://jjssp.e-jikei.org/ARCHIVES/vol04no01/JpnJSSP_vol04_no01_p01.pdf

[4] WHO Coronavirus disease (COVID-19): Herd immunity, lockdowns and COVID-19 https://www.who.int/news-room/q-a-detail/herd-immunity-lockdowns-and-covid-19

[5] J. Wang and G. Du, "COVID-19 may transmit through aerosol", ***Irish Journal of Medical Science***,Vol. 189, pp.1143-1144, 2020. https://doi.org/10.1007/s11845-020-02218-2

[6] Y. Fujii, A. Takita and S. Hashimoto, "A Helmet Type Mask "Distancing-Free Mask": An Engineering Solution that Eliminates the Lockdown", ***Journal of Mechanical and Electrical Intelligent System***, Vol.3, No.3, pp.1-7, 2020. http://jmeis.e-jikei.org/issue/archives/vol03_no03/F001/Camera_ready_manuscript_JMEIS_F001_535362_final.pdf

[7] Y. Fujii, A. Takita and S. Hashimoto, " An engineering approach for fighting COVID-19; Pseudo herd immunity through the complete spread of the helmet-type masks", ***Journal of Mechanical and Electrical Intelligent System***, Vol.4, No.1, pp.1-5, 2021. http://jmeis.e-jikei.org/ARCHIVES/v04n01/JMEIS_v04n01a001.pdf

[8] Y. Fujii, A. Takita, S. Hashimoto and T. Yamaguchi, ***Japanese Patent Application***, No. 2020-113097.

[9] Y. Fujii, A. Takita and S. Hashimoto, ***Japanese Patent Application***, No. 2020-177304.