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Personal Respiratory Air Purification Device (Booth-type): Distancing-Free Booth (Prototype No.1)

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Abstract. The Distancing-Free Booth, which is an inexpensive and high-performance booth-type respiratory air purification device, has been developed. This is a variation of Distancing-Free Mask, which has been developed by the authors as an inexpensive and high-performance helmet-type respiratory air purification device. Anyone, who uses Distancing-Free Booth and Mask all the time when he/she is outside his/her home, he/she can be allowed to go out freely even when the lockdown is deemed necessary. We propose a new social system, in which the lockdown is not needed, by means of spreading these 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 inexpensive and high-performance booth-type respiratory air purification devices, the Distancing-Free Mask (helmet-type) [6,7,8] and the Distancing-Free Booth (booth-type), which is reported in this paper. This proposal is based on the following 3 simple ideas/hypothesis.

[a] Mass production of inexpensive and high-performance booth-type/mask-type respiratory air purification devices, which shield viruses 100%, might be easy with the modern technology.

[b] Anyone, who usees Distancing-Free Booth and Mask all the time when he/she is outside his/her home, he/she can be allowed to go out freely even when the lockdown is deemed necessary.

[c] Considered in the same way as herd immunity, the devices using 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”. This booth-type device, which is the variation of the Distancing-Free Mask [6,7,8] and based on the inventions made by the authors [9,10], is described in this paper.

2. Distancing-Free Booth (Prototype No.1)

Features of the personal virus-free space "Distancing-Free Booth" are as follow,

[1] The frame of the vinyl chloride pipes is covered with a vinyl sheet to create an airtight structure. The doorway can be opened and closed with a fastener.

[2] The air purified by the pump and the non-woven fabric filter, which removes at least 99.97% of particles of the air down to at least 0.3 μm in size, is forcibly supplied by the air supply unit and forcibly exhausted by the exhaust unit.

[3] Air leakage from the fastener is estimated to be up to approximately 5% of the supply and exhaust air flow rate.

[4] When the internal pressure is set to positive value, it is estimated that the air supply shielding rate (of fine particles down to 0.3 μm) is 99.97% and the exhaust shielding rate (of fine particles down to 0.3 μm) is 95%.

[5] When the internal pressure is set to negative value, it is estimated that the air supply shielding rate (of fine particles down to 0.3 μm) is 95% and the exhaust shielding rate (of fine particles down to at 0.3 μm) is 99.97%.

[6] The maximum flow rate of air supply is large enough at 2,000 L/min. The internal carbon dioxide concentration is suppressed to about +500 ppm or less compared to that of outside. The acoustic characteristics are at a level where the user can normally talk to the outside.

[7] Setting of target differential pressure and power of the exhaust pomp and monitoring of flow rate, differential pressure, and carbon dioxide concentration (internal and external) can be done via Bluetooth on smartphones or PCs.

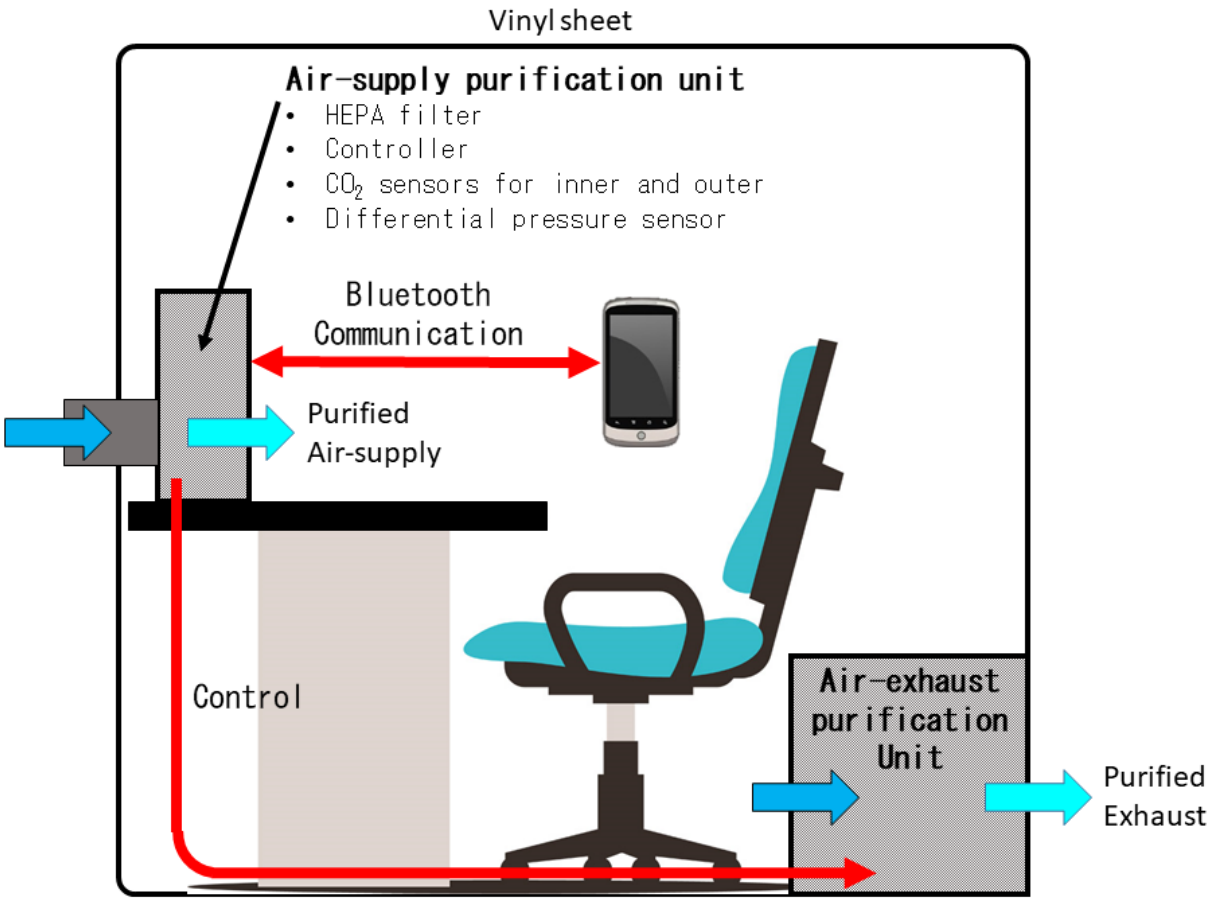

Fig.1 Schematics of “Distancing-Free Booth”

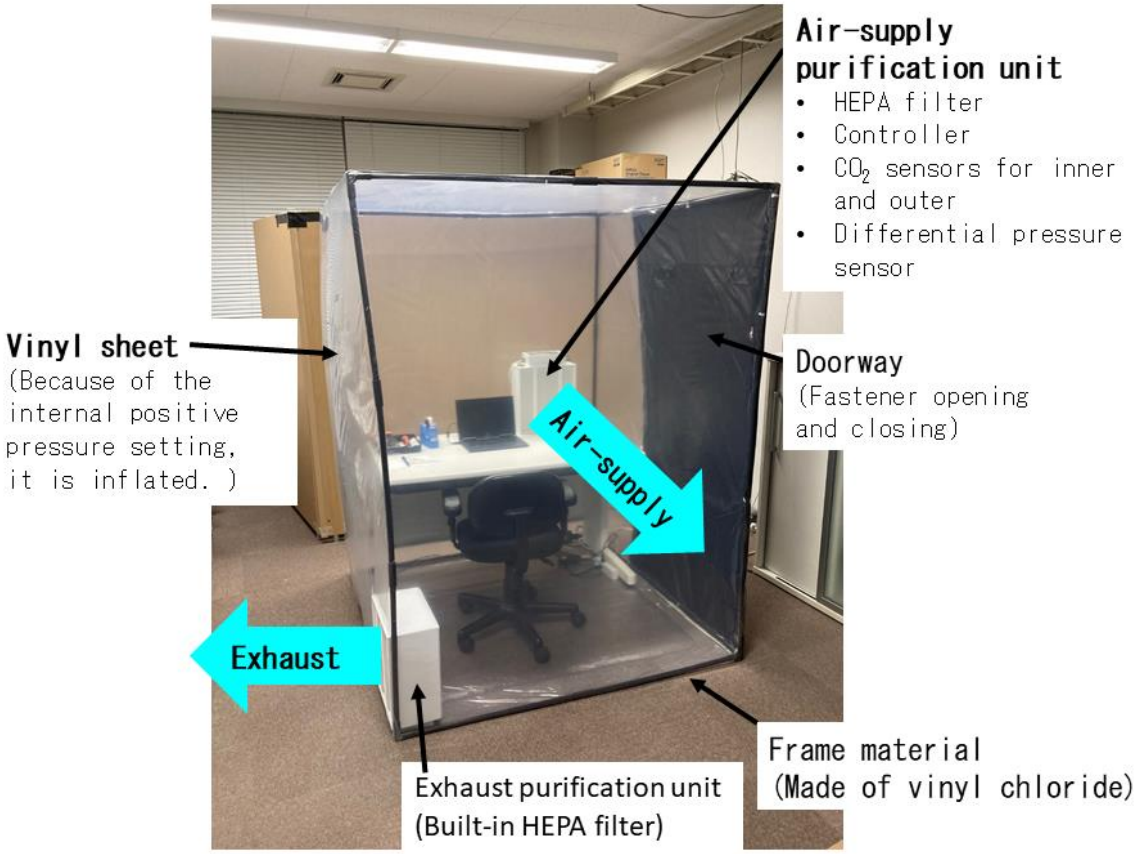

Fig.2 Photograph of “Distancing-Free Booth”

Table 1. Specifications of the prototype Distancing-Free Booth (Prototype No.1)

Dimensions (booth body):	140 cm (W) x 140 cm (D) x 180 cm (H)
Dimensions (air-supply unit):	31 cm (W) x 15 cm (D) x 41 cm (H)
Dimensions (exhaust unit)	31 cm (W) x 18 cm (D) x 38 cm (H)
Mass of Air-supply unit	1.5kg
Mass of Exhaust unit	1.3kg
Maximum air supply flow rate	2,000 l / min at 2 Pa
Parts cost	320 USD.
Expected cost of mass-produced products	140 USD

Figure 1 shows a schematic diagram of the prototype of the Distancing-Free Booth. Figure 2 shows a photograph of the Distancing-Free Booth. The Distancing-Free Booth has an airtight structure. The specifications of the prototype are shown in Table 1.

As for the air supply, the outside air filtered is pumped through a filter unit by an electric pump (model: 9BFB12P2H003, manufacturer: Sanyo Denki Co. Ltd.). 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. The total area of the non-woven filter embedded in the air-supply unit is approximately 6,000 cm^2.

As for the exhaust, the inside air filtered is pumped through a filter unit by an electric pump (model: 9BMB12P2K0, manufacturer: Sanyo Denki Co. Ltd.). The same 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. The total area of the non-woven filter embedded in the exhaust unit is approximately 6,000 cm^2.

Leakage to the outside air through the gap around the fastener 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 as follows,

[a] When the internal pressure is set to positive value, it is estimated that the air supply shielding rate (of fine particles down to at least 0.3 μm) is 99.97% and the exhaust shielding rate (of fine particles doen to at least 0.3 μm) is 95%.

[b] When the internal pressure is set to negative value, it is estimated that the air supply shielding rate (of fine particles down to at least 0.3 μm) is 95% and the exhaust shielding rate (of fine particles down to at least 0.3 μm) is 99.97%.

The carbon dioxide concentrations inside and outside the booth 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 booth 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 for each unit, i.e, the air-supply unit or the exhaust unit.

The controller (model: ESP32 DevKit, manufacturer: Espressif System Co. Ltd.) controls the pump output of the air-supply unit as follows.

[1] The pressure reaches the set pressure, which is typically +2 Pa.

[2] If the carbon dioxide concentration does not meet the condition of [external concentration + 500 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.

Figure 3 shows an example of the time series of the differential pressure inside the booth to the outside, the flow rate of the air supply, and the carbon dioxide concentration inside and outside the booth when the user stays in the booth. The measurements are shown from approximately 35 minutes after the booth is closed. The average value of the differential pressure inside to outside the booth is 2.00 Pa, the standard deviation is 0.02 Pa, and the set value is 2.0 Pa. The mean flow rate is 1.25×10^3 (l / min) and the standard deviation is 0.01×10^3 (l / min). The mean and standard deviation of the carbon dioxide concentration inside the booth are 1.04×10^3 ppm and 0.05×10^3 ppm, respectively. The mean and standard deviation of the carbon dioxide concentration outside the booth are 0.83×10^3 ppm and 0.04×10^3 ppm, respectively. In this staying experiment, it was confirmed that the user could talk with the outside people without any acoustic problem.

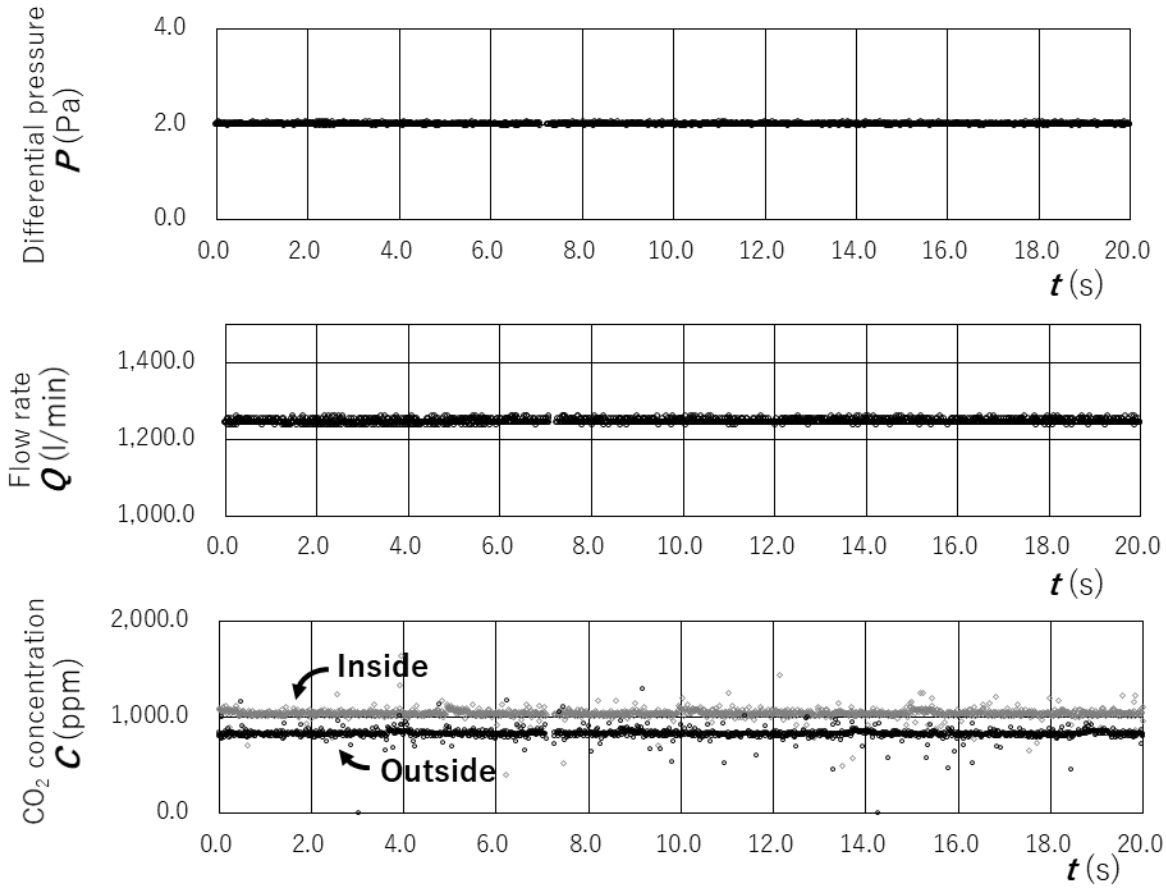

Fig. 3 Time series of control parameters during the operation

3. Discussions

Like other viruses, the new coronavirus (SARS-CoV-2) cannot infect uninfected individuals with just one virus. More than a certain number of viruses are required. People can be prevented from getting infected by making the probability of inhaling the virus sufficiently small. The authors propose to drastically reduce the number of viruses that people take in their daily lives by the following methods.

[1] When going out, each person wears the Distancing-Free Mask.
The ratio of the time spent wearing the Distancing-Free Mask to the total time of going out is set to a certain level or more. Since the air has not been sufficiently replaced for a certain period of time after wearing the mask, it is considered not to wear the mask during the period.

[2] When working in the office, each person enters the Distancing-Free Booth.
The ratio of the time spent staying in the Distancing-Free Booth to the total time of staying n the office is set to a certain level or more. Since the air has not been sufficiently replaced for a certain period of time after entering the booth, it is considered not to stay in the booth during the period.

For example, a fairly severe infection spread situation with an effective reproduction number $\boldsymbol{R_t}$ = 2.0. The effective reproduction number $\boldsymbol{R_t}$ represents the number of people newly infected by one infected person during that person's infection period. If the number of uninfected persons taking up the virus in their daily lives can be drastically reduced and the probability of infection can be reduced to 1/4, the effective reproduction number $\boldsymbol{R_t}$ = 2.0 / 4 = 0.5, and the number of infected people is halved for each infection period (approximately a few weeks).

This time, the booth type covers the individual desk and chair of the office. It can be applied to various forms such as the following.

[1] Bed unit: A form in which the bed of a person at high risk of aggravation is covered.

[2] Room unit: By replacing the ventilation system in a private room of a hospital, a guest room of a hotel, and a room of a general house, the entire room can be made into a space where the air is purified like the Distancing-Free Booth.

[3] Seat unit: A form in which the seats of an aircraft, train, bus, or private car are covered.

[4] Others: A form that covers the stroller. A form that covers a wheelchair.

[5] In a hospital room, if there is an infected person inside, or if users want to use it for the purpose of protecting the outside from the inside, the inside pressure can be set a negative value. As a result, even if there are minute gaps, the air flow in the gaps is “outside to inside".

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. We believe that proposed measures against COVID-19 can change the current situation in which the economy and culture continue to suffer enormous damage.

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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 and A. Takita, " Personal respiratory air purification device (helmet-type): Distancing-Free Mask (Prototype No.5)", ***Journal of Mechanical and Electrical Intelligent System***, Vol.4, No.2, pp.1-5, 2021.
http://jmeis.e-jikei.org/ARCHIVES/v04n02/JMEIS_v04n02a001.pdf

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

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