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Low-Cost Powered Air-Purifying Respirator (PAPR) "Distancing-Free Mask Frontline (DFM-F) Prototype No.1" for the Operational Tests in Hospitals in Cebu City, Philippines

Ronald M. Galindo[1,a], Akihiro Takita[2,b], Edwin Carcasona[3,c], Ethelda Magalang[4,d], Tabetha S. Galindo[5,e], Seiji Hashimoto[2,f], Takao Yamaguchi[2,g], Edgar U. Tibay[1,h], Dongwei Shu[6,i], Haruo Kobayashi[2,j], Kenji Amagai[2,k], Naoya Ohta[2,l], Noriaki Yoshiura[7,m], Anna Kuwana[2,n], Ayako Yano[2,o], and Yusaku Fujii[2,p,*]

[1]Faculty of Engineering, Cebu Technological University, Cebu, Philippines
[2]School of Science and Technology, Gunma University, Kiryu, Japan
[3]Faculty of Engineering, University of San Carlos, Cebu, Philippines
[4]Cebu Doctor's College of Medicine, Cebu, Philippines
[5]Obstetrics and Gynecology Department, Visayas Community Medical Center, Cebu, Philippines
[6]Nanyang Technological University, Singapore, Singapore
[7]Department of Information and Computer Sciences, Saitama University, Saitama, Japan

*Corresponding author

[a]<ronald.galindo@ctu.edu.ph>, [b]<takita@gunma-u.ac.jp>, [c]< edcarc123055@yahoo.com>, [d]<etheldacarmelamd@gmail.com>, [e]<tabetha7762@yahoo.com>, [f]<hashimotos@gunma-u.ac.jp>, [g]<yamagme3@gunma-u.ac.jp>, [h]<edgar.tibay@ctu.edu.ph>, [i]< mdshu@ntu.edu.sg>, [j]<koba@gunma-u.ac.jp>, [k]<amagai@gunma-u.ac.jp>, [l]<ohta@gunma-u.ac.jp>, [m]<yoshiura@fmx.ics.saitama-u.ac.jp>, [n]<kuwana.anna@gunma-u.ac.jp>, [o]<yano@gunma-u.ac.jp>, [p]<fujii@gunma-u.ac.jp>,

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Abstract. A low-cost and comfortable PAPR with high shielding rate for aerosols, "The Distancing-Free Mask Frontline (DFM-F) Prototype No.1" which is suitable for the test use by the medical staffs in hospitals in Cebu city, Philippines, is developed. This development is done in Cebu, Philippines under an international research collaboration project between Philippines, Singapore, and Japan researchers, in which the vaccine-independent and lockdown-free society/nation by means of spread of low-cost PAPR, is proposed and pursued. The present status and future prospect of DFM-F project in the whole DFM project are discussed.

1. Introduction

For more than 2 years, as measures against COVID-19, securing social distancing and obliging to wear masks have been implemented, but the situation, where the spread of infection cannot be stopped, have repeatedly occurred, and lockdown has been carried out every time that has caused enormous damage to the society. As a complete solution, the acquisition of herd immunity by vaccination is sought after all over the world. However, there is not a good prospect of promptly developing, producing, or spreading an effective vaccine when a newly mutated variation of SARS-CoV-2, against which the existing vaccines are not sufficiently valid, appears. [1,2]

Among the COVID-19 infection routes, contact infection and oral infection are relatively easy to prevent by enforcing hand washing and food hygiene management. It is thought that droplet infection and airborne infection are the main infection routes that are difficult to prevent. [3,4]

Droplet infection is an infection route that is transmitted by inhaling the virus contained in droplets, which are particles with a diameter of 5 μm or more that are excreted by coughing or vocalization. Airborne infection is an infection route in which a virus contained in an aerosol, which is a particle with a diameter of 5 μm or less, is inhaled by breathing.

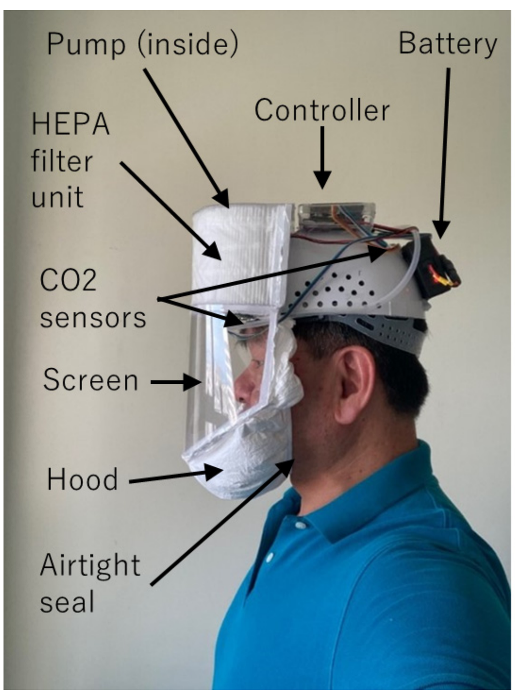
A face mask can capture most of droplets with a large particle size at the time of discharge. However, aerosols, which are small particles, easily leak to the outside through the gap between the mask and the face, make countermeasures difficult. [5]

Since droplets with a large particle size fall at a high speed due to gravity, it is thought that most of them can be prevented by securing social distancing. However, aerosols are easy to diffuse widely in the air, and it is difficult to remove the released aerosols from the air. [6]

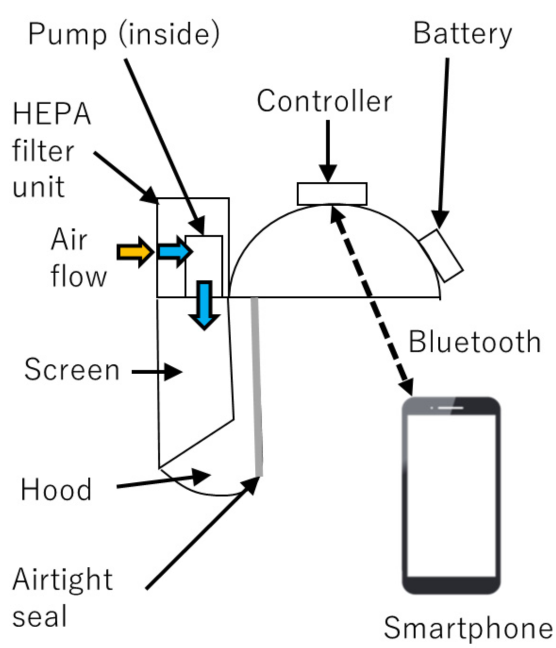
There is a non-woven fabric filter as a device that shields aerosols. However, the sufficient measures to prevent leakage from gaps are usually not taken. Face masks used by the general public tend to have gaps between them and the face, and most of the breathing air goes in and out through the gaps.

As for wearable-type high-performance Powered Air-Purifying Respirator (PAPR), medical PAPRs and industrial PAPRs are commercially available. However, they are designed to be used by special people in special environments and are expensive and uncomfortable. Therefore, in order to show that an inexpensive and comfortable high-performance PAPR can be realized, we have developed the prototypes of the "Distancing-Free Mask" [7] and the "Distancing-Free Booth" [8].

In this paper, a low-cost and comfortable PAPR with high shielding rate for aerosols, "The Distancing-Free Mask Frontline (DFM-F) Prototype No.1" which are developed for the test use by the medical staffs in the hospitals in Cebu city, Philippines, is described. This development is done in Cebu, Philippines under an international research collaboration project between Philippines, Singapore, and Japan researchers, in which the vaccine-independent and lockdown-free society/nation by means of spread of low-cost PAPR, is proposed and pursued [9]. The present status and future prospect of DFM-F and the project are discussed.



(a) Photo of DFM-Frontline



(b) Drawing of DFM-Frontline

Fig. 1. Photo and drawing of Distancing-Free Mask Frontline (DFM-F) Prototype No.1

2. Distancing-Free Mask Frontline (DFM-F) Prototype No.1

Fig.1 shows the photo and drawing of Distancing-Free Mask Frontline (DFM-F) Prototype No.1. The features of the DFM-F No.1 are as follows.

[1] A helmet-type mask with an airtight structure by a chin strap, which is based on a light work helmet and is composed of non-woven fabric and vinyl chloride sheet.

[2] Ears are exposed, so that communication with surrounding persons is easy. Easy to put on and take off by means of front entry with the chin strap.

[3] The outside air purified by a pump and a non-woven fabric filter (99.97% shielding of fine particles up to 0.3 μm) is supplied to the inside of the helmet.

[4] The internal pressure is kept to a positive value by the pump controlled by the controller. Therefore, the intrusion of outside air through a small gap that may be formed in the chin strap seal is prevented. It is estimated that the air supply shielding rate $\boldsymbol{S}_{\mathbf{r,in}}$ is 99.97%.

[5] The air inside is exhausted through a non-woven fabric filter due to the pressure difference between the inside and outside.

[6] Leakage of internal air from the neck seal is estimated to be up to 5%.

[7] The supply air flow rate is large enough at approximately 400 L/min. The internal carbon dioxide concentration is suppressed to about +1,000 ppm or less compared to that of outside.

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

[9] The total weight is about 772g, including the battery that enables continuous operation for about 8 hours.

[10] The total cost of parts for the prototype is approximately $ 300. In the case of mass production, it will be approximately 100 dollars or less.

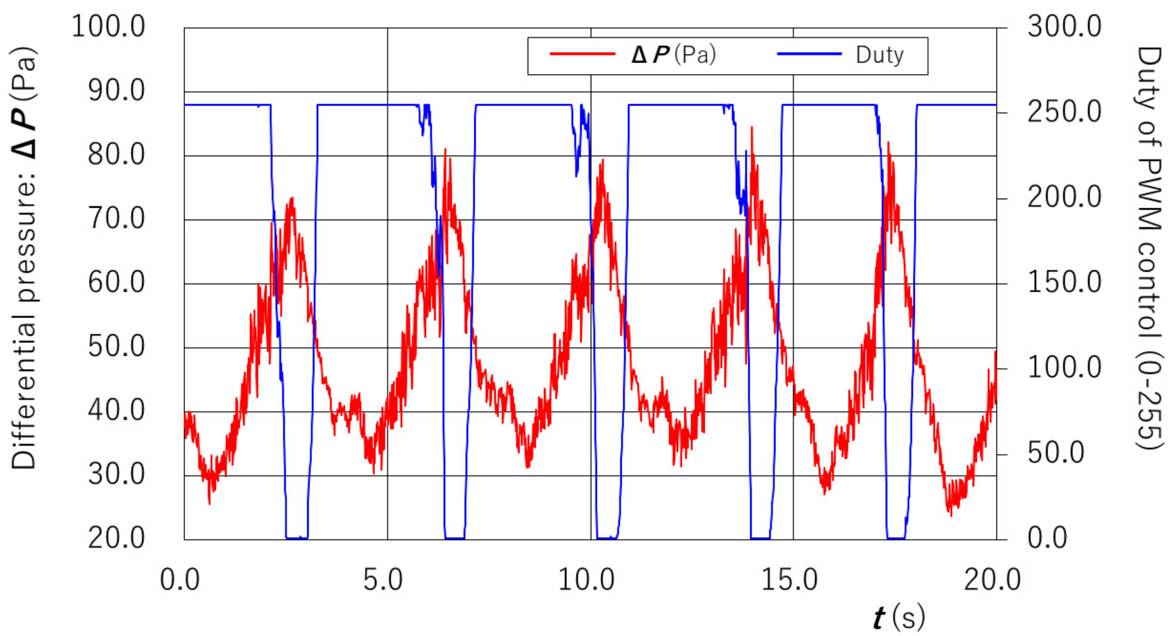


Fig. 2. Change in the differential pressure ΔP and the duty of PWM control in an operational test of Distancing-Free Mask Frontline (DFM-F) Prototype No.1.

Fig. 2 shows the Change in the differential pressure $\boldsymbol{\Delta P}$ and the duty of PWM control in an operational test of Distancing-Free Mask Frontline (DFM-F) Prototype No.1. The duty of PWM (Pulse Width Modulation) control of the pump is based on the following simple equation.

Duty(i+1) = Gain * $\Delta \boldsymbol{P}$ (i),

where Duty(i) is the duty of i-step of the control loop, Gain is set to 2.0, and $\Delta \boldsymbol{P}$ (i) is the differential pressure of the inside to the outside of the helmet of i-step of the control loop. The range of Duty(i) is 0 to 255.

The duty increases when the differential pressure $\Delta \boldsymbol{P}$ becomes lower than the target value of 60 Pa, and the duty decreases when the differential pressure $\Delta \boldsymbol{P}$ becomes higher than 60 Pa

Distancing-Free Mask Frontline (DFM-F) Prototype No.1 is developed for operational tests, in which DFM-Fs are used by the medical staffs in hospitals in Cebu city, Philippines. This development is done mainly in Cebu Technological University (CTU), Philippines under an international research collaboration project between Philippines, Singapore, and Japan researchers, in which the vaccine-independent and lockdown-free society/nation by means of spread of low-cost PAPRs, is proposed and pursued.

The developed prototype “DFM-F Prototype No.1” will be tested and improved in the laboratory and then evaluated in the operational tests in the hospitals.

3. Discussions

The author proposes a social system, which has an ability to reliably converge infection without lockdown in situations when the acquisition of herd immunity through vaccination is not in time, as shown below.

[A] Distribute helmet-type PAPRs to all citizens.

[B] If there is concern about the spread of infection, the government does the followings.

[B.1] Estimate the effective reproduction number $\boldsymbol{R}_{\mathbf{t}}$ at that time.

[B.2] Set the target of the effective reproduction number $\boldsymbol{R}_{\mathbf{t\_target}}$.

[B.3] The "Required Usage-Rate $\boldsymbol{U}_{\mathbf{r\_required}}$ " required to realize the target effective reproduction number $\boldsymbol{R}_{\mathbf{t\_target}}$ is calculated by solving the equation, which is derived based on appropriate assumptions.

[C] Show $\boldsymbol{U}_{\mathbf{r\_required}}$ and oblige all citizens to fulfill it. $\boldsymbol{U}_{\mathbf{r\_required}}$ for the vaccinated persons can be a smaller value.

[D] Watch the transition of the effective reproduction number, and if the target is unlikely to be achieved, raise $\boldsymbol{U}_{\mathbf{r\_required}}$. On the other hand, if the results exceed the target, $\boldsymbol{U}_{\mathbf{r\_required}}$ will be reduced to increase the freedom of life of the citizens.

[E] Even if the estimation of $\boldsymbol{U}_{\mathbf{r\_required}}$ is greatly wrong and the worst situation occurs, the spread of infection can be stopped promptly at any time simply by setting $\boldsymbol{U}_{\mathbf{r\_required}}$ to 100%. Therefore, various trials can be performed with a margin.

In order to surely implement the above [C], it will be effective to build a "Usage-rate Net Management System" linked with a smartphone, which has a function to measure and certify each person's "Usage-rate $\boldsymbol{U}_{\mathbf{r}}$ ". This system can prove if each citizen is fulfilling the obligation of "Required Usage-rate $\boldsymbol{U}_{\mathbf{r\_required}}$ ". Within the condition of fulfilling obligation, each citizen can be given a right to freely select "opportunity for interpersonal contact without using the devices", for example, "restaurant" or "party".

As a simple example of the definition of "Usage-rate $\boldsymbol{U}_{\mathbf{r}}$ ", “Ratio of device wearing time to outing time” can be considered. Instead of this definition, it could be defined as the "estimated value of the number of viruses inhaled by respiration a day", which is estimated from the estimated value of the virus concentration in the surrounding environment and the estimated value of the virus shielding rate of PAPR.

In the future, when various PAPRs with excellent comfort are developed and released and become available at low prices, many people might want to breathe purified clean air using these PAPRs, regardless of the request from the government. A society, in which many people always seek "purified air" as well as “purified water” and use personal PAPRs, is extremely resistant to all airborne infectious diseases.

4. Concluding Remarks

A low-cost and comfortable PAPR with high shielding rate for aerosols, “The Distancing-Free Mask Frontline (DFM-F) Prototype No.1” which is suitable for the test use by the medical staffs in hospitals in Cebu city, Philippines, is developed. This development is done in Cebu, Philippines under an international research collaboration project between Philippines, Singapore, and Japan researchers, in which the vaccine-independent and lockdown-free society/nation by means of spread of low-cost PAPR, is proposed and pursued.

Through the development and test of the Distancing-Free Mask Frontline (DMF-F) for medical staffs, highly safe environments can be provided to the medical staffs/workers and the medical function in the nation can be much strengthened.

The technology and knowledge obtained by developing DMF-F will be utilized in the development of the Distancing-Free Mask Public (DFM-P) for general public as lower-cost, more comfortable and cooler designed one for our final target, i.e., the creation of a vaccine-independent and lockdown-free society/nation.

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