Use of reverse engineering method for respirator devices in COVID-19 crisis

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***Abstract*—In this research paperwork, we will present the utility of reverse engineering to implantable assistance systems and rehabilitation technology in the medical field. According to the fast and widespread in COVID-19 contagion in the world, air respirator system demand increased in with high cost with less availability. In this urgent case, reverse engineering is the right solution at a low price and short time to save the people in need of fighting COVID-19, as it is the essential tool of the first defense line. Reverse technology meany new ideas that can save human beings in a crisis, mainly in the medical field, quarantine, and hospitals. 3D printing is the best solution and low cost with a short time of prototyping, for most of the new research area. We need to redesign portable air-purifying with lightweight, long time battery, three airflow speeds with the antifog hood shield. Our main object to contribute humanity against the virus no to financial gain.**

***Index Terms*—Reverse engineering, COVID-19, Respirator, 3D printing, Airflow, RMVS, PWM, Fan speed control**

I. Introduction

Since December 2019, a significant drop in medical materials, such as face shields, ventilators, and masks, in the Global [1]–[3]. In response, several engineering teams to assess their current and expected needs. Many technical teams are thinking about how they could print critical medical supplies as part of the organizations response to the COVID-19 pandemic [4], [5]. FAB LAB Qatar, as well as the division of mechanical engineering, have been researching devices that they could cooperate on to try to meet coronavirus crisis demand. The need for health care products clinical resources needed to care for patients with COVID-19 increases. There are limitations of critical medical supplies and equipment worldwide [6]–[8]. Europe, US, middle east, and FabLab foundation teams across open source platforms are working together to reverse-engineer, a lot of medical products like 3D-print face shield, masks, and ventilator for corona patient care [9]. In this research, we will present the utility of reverse engineering to decrease the impact of the COVID-19. We are creating a new strategy focused on the work we are doing to evaluate and potentially reverse-engineer replacement powered air-purifying respirator, as shown in Figure 1. This engineering solution would be fast away to tackle the virus COVID-19.

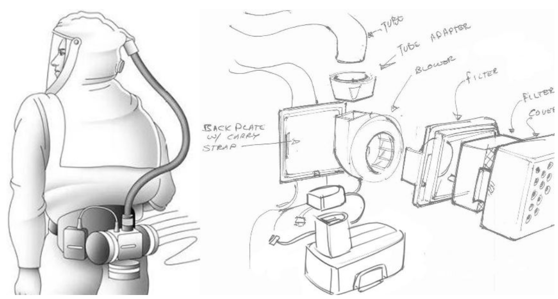

Fig. 1. Powered air purifying respirator

II. Reverse engineering of respirator device

COVID-19 proved that reverse engineering comprises any action you do to determine how a medical device or to understand the ideas and techniques that mainly used. Reverse engineering is a logical approach for evaluating the design of existing medical devices to tackle the virus [10], [11]. In our cases, we can use it an initial step in the redesign process of the ventilator, to do any of the following:

- Observe and evaluate the mechanisms that make the respirator work.
- Analyze and study the inner components of the respirator. (Electrical and Mechanical)
- Develop the part or product geometry in a CAD model from the original medical devices.
- Remaking the electronic PCB board and any mechanical parts.

Before COVID-19, you decide to re-engineer a device and make every effort to obtain technical data. Because of the global crisis and the significant demand for medical products, reverse engineering is considered one of the best solutions to protect humanity from coronavirus danger [12]. The powered air-purifying respirator consists of many parts, as shown in Figure 1:

- Blower airflow: 6 CFM (Min) and 8 CFM (Max)
- PCB motherboard and speed controller
- Filters and breathing tube
- Headcover and Helmet
- Battery 11.1V/4.8AH

In this research, we will make and fabricate all these parts, and try to match them.

III. Re-design and Fabrication phase

In this part, we will examine all phases of the reverse engineering fabrication part, starting from the blower to the 3D package and sewing the headcover (Full hood).

A. Airflow measurement and analysis

This paper presents an analysis of the output of airflowthe model used for analyzing the influence of the airflow inside the head hood. We have measured the airflow from the first device to know the strength of the flow, and we have measured the airflow of our air blower, respectively are shown in Figures 2 and 3. The soft air distribution on the head hood airflow sensor concerning the airflow rate and relative humidity of air is computed for system stability [13], [14]. By comparing the results with the dry air situation, the conclusion is making. The moisture in the air will decrease the temperature of the upstream and downstream resistance and increase the temperature difference between the two resistances and the motor's power consumption. Table I showed the airflow measurement for the first device and the reverse engineering device.

TABLE I
Airflow measurement

Airflow Speed	Original device	Reverse engineering device
Speed 1	6 CFM	6 CFM
Speed 2	8 CFM	8 CFM
Speed 3	-	10 CFM

Fig. 2. Original devices airflow measurement without HE filter

B. Filters

The filters of powered air-purifying respirators play several vital roles. Screens placed in several possible positions in the purifying respiratory circuit. Filtration from the bacteria and COVID-19 viruses and protecting healthcare patients. In our reverse engineering device, we do not care about the fabrication of indoor filters as we will purchase a ready-made filter (HE Filter TR-3712N) [15].

Fig. 3. Reverse engineering airflow measurement without HE filter

C. Motherboard and speed controller of the blower

The electronics part it's the most critical part of the devices via the speed of the blower and the battery management of the system [16]. In our research paper, our reverse engineering for respiratory design has three parts, as shown in Figure 4.

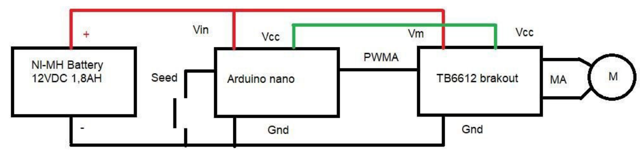

Fig. 4. The block diagram of the ventilator device

We have to control blower speed to get proper airflow for head cover air circulation [17]. We are using PF97331BX-B00U-A99 blower motor as Centrifugal DC Blower, 12VDC, 54.7CFM, 42W, 63.2dBA, 6800RPM. We use Arduino nano with a TB6612FNG DC-motor driver to control blower speed with a PWM control signal of 25KHz with a pk voltage of 5vdc and a programable duty cycle to control blower speed according to mode switch in three different speed levels. For accurate PWM 25KHz frequency, we used the Arduino built-in timer to generate the PWM signal, as shown in Figure 5.

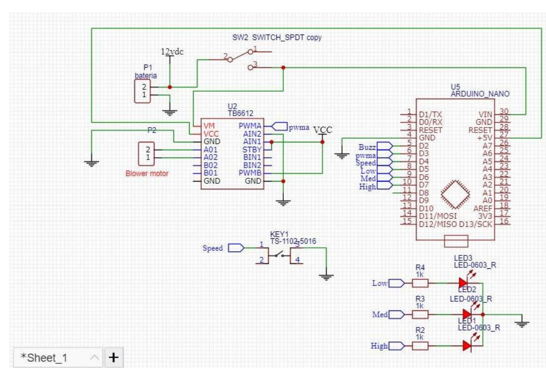

Fig. 5. Electronics schematic

Timer frequency is defined by the selected Prescaler, where:

$$25KHz = \frac{16MHz}{Prescaler \times (TOP + 1)} \qquad (1)$$

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$$Prescaler \times (TOP + 1) = \frac{16MHz}{25KHz} = 640 \quad (2)$$

If we select a prescaler of 8, we get that:

$$TOP + 1 = \frac{640}{8} = 80 \quad (3)$$

According to Equ. 3 and 4, TOP = 79 to summarize, using Arduino running at 16 MHz, and use an 8-bit timer 2 to generate a 25 kHz PWM with a Prescaler of 8 (TCCR2B = 0x09) and a TOP of 79 (OCR2A = 79). Then we change the duty cycle during timer running using OCR2B register [18], [19]. The output PWM signal with 25kHz and 30% duty cycle, as shown in Figure 6.

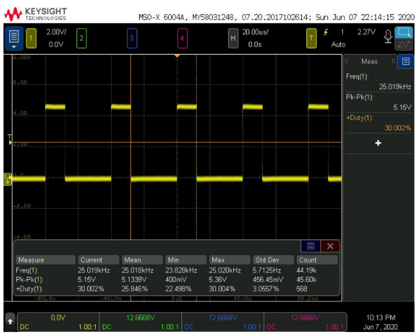

Fig. 6. Duty cycle 30% high speed 10 CFM

According to practical measurements of our reverse design in Figure 7, our system runs with a battery of 12vdc 1.8Ah. If blower working continuously in high-speed level 3 (PWM signal 25KHz with duty cycle 30%), it will draw 0.45 A dc. The battery at least will stay for 4 hours. There are numerous

Fig. 7. System practical electrical measurement

PCB fabrication techniques available for prototyping. The method used here to fabricate rapid PCB. This work aims to make a low-cost PCB manufacturing, as shown in Figure 8. The standard PCB prototyping equipment is manufactured and tested for its performance.

So powered air-purifying respirator operation will be like: Power on wait mode select, After mode switch, pressed it will start blowing air with low speed (6 CFM). 2nd press will select a medium speed (8 CFM), 3rd press will choose the high speed (10 CFM). Another push will stop blower and go in wait mode select again.

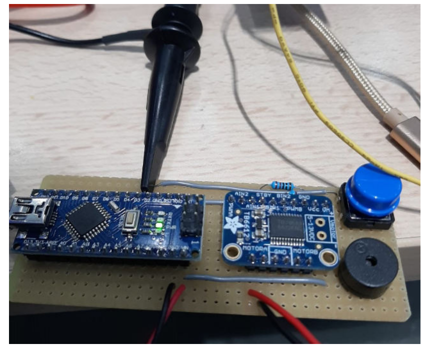

Fig. 8. PCB fabrication

IV. Prototyping and Testing Phase

Many reverse engineering tools concentrate on extracting the structure or architecture of a legacy system to transfer this information into the minds of the engineers trying to maintain or reuse it. In our case, we are working on a medical device to help humanity in a critical time. After the electronics phase and the airflow calculation, there are steps necessary in the reverse engineering circle. The package and the 3D design of the device should respect the medical fabrication standard, as shown in Figure 9. After 3D printing using FDM technology should fix the different components (PCB, Blower, motor controller, battery, and HE filter) inside the Box for check and validation.

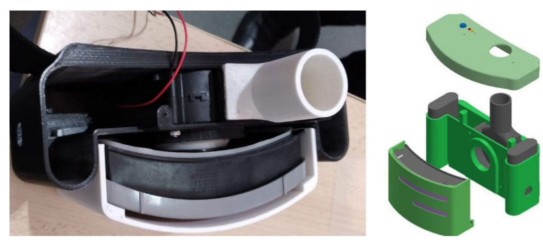

Fig. 9. Assembled the medical device prototype

Everyone's face and head are different, so how is one eyewear model fit everybody. With the 3D design of the headbands, we've carefully avoided sensitive areas of the head while designing self-adapting twin pads for the browband, as shown in Figure 10. We used waterproof Non-Woven material with

Fig. 10. Manufacture of the hood (Headcover)

anti-fog precise view acrylic thickness 0.3 mm to fabricate the hood with low weight within 90 gm, as shown in Figure 11. In this prototype, we are sure that we can see easily around us, available head and a lightweight air-purifying respirator to breathe fresh air. Our device is the same as the original one; our helmet is a little more weight, and our headcover is less than the original equipment, as shown in Table II. The stage

TABLE II
TOTAL WEIGHT OF THE POWERED AIR PURIFYING RESPIRATOR

Parts	Original device	Reverse engineering device
Respirator casing	1200gm	1200gm
Helmt	200gm	270gm
Head cover	100gm	90gm

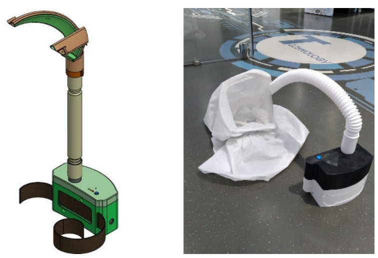

Fig. 11. A 3D full system of the reverse engineering powered air-purifying respirator

of testing and wearing the device, as shown in Figure 12.

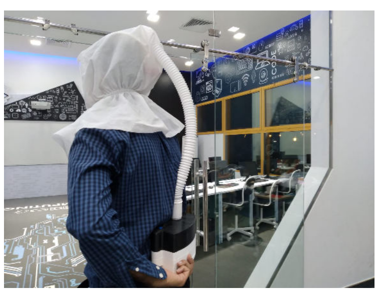

Fig. 12. The stage of testing and wearing the device

CONCLUSION

In this paper, we approved that with reverse engineering, we redesign new local respirator with more airflow lightweight and anti-fog hood shield using available resources in FabLab in a short time and low cost. In this research, we made, and we tested the reverse engineering respirator, the essential tool of the first defense line. We proved the reverse engineering in medical device a right solution in COVID-19 crisis. Future, we will work on making respirators less weight, longer battery lifetime, more airflow at a low price and increase filter efficiency with long life time using bipolar ionization technique.

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