A Customized Smart Medical Mask For Healthcare Personnel

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Abstract - **A medical mask is one of the vital Personal Protective Equipment (PPE) used by Healthcare Personnel (HCP) to protect themselves, patients, and others while providing their essential services to the public. HCPs all around the world are fighting on the frontlines of COVID-19. While they are saving people's lives from Coronavirus, it is also critical to monitor the HCPs' health conditions continuously. In this study, we propose a framework to develop a customized smart medical mask system to monitor the HCP's temperature and strain on the face. Aerosol Jet Printing (AJP) technology is applied to develop the mask that embeds 3D printed sensors with wireless function. The proposed design process utilizes a 3D scanned picture of an individual face, then analyzing its geometrical attributes to determine the adjusted places for the sensors on the mask and optimize the design paramenters of the sensors. The two types of sensors, temperature, and strain are fabricated using the AJP technology. The temperature monitoring is to detect respiratory breathing fever and irregular, which is one of the symptoms of respiratory diseases. And strain monitoring is for alarming possible face irritation and bruising caused by tight sealing of masks. The sensing data is transmitted to the cloud for real-time monitoring purposes. This paper showcases the customized yet affordable additive manufacturing built on the Internet of Things technology for a personalized healthcare application to alarm workload and body condition of HCP.**

Keywords - **3D printing, customized sensors, healthcare personnel, real-time monitoring systems, smart medical mask**

I. INTRODUCTION

The coronavirus pandemic (a.k.a. COVID-19) has changed the way we live. It has been described as the most significant worldwide crisis since the Second World War [1]. Healthcare Personnel (HCP) such as doctors and nurses have positioned at the pandemic battlefront. Fatiguing, overwhelmed, long shifts for the COVID-19 related tests and treatments have been continued as the Coronavirus spreads globally.

Regardless of stringent rules on Personal Protective Equipment (PPE), improved resource availability, and high technical standards to design PPEs; still, the HCP is vastly vulnerable to the recent world outbreak, the COVID-19. The risk of viral transmission and the overall mortality rate of HCPs have been reported and analyzed [2].

A medical mask is one of the pivotal PPE used by HCPs. It reduces biological risks, such as viral transmission and infections [3]. However, prolonged use of the mask can cause skin irritation and notable skin damage. As shown in Figure 1, recently, health care workers around the world shared their face selfies to urge people to stay at home. Their actions have been believed to be influential in limiting the spread of the Coronavirus in public.

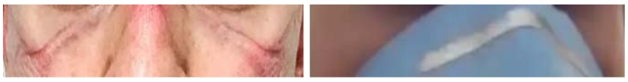


Figure 1 Faces of medical professionals bruising from wearing a mask long time to fight on the frontlines of COVID-19. Source: Adapted from [4].

The HCPs are putting themselves in harm both mentally and physically; there is a need to track the HCPs health conditions while they are carrying out their essential tasks for the public. Hence, in this study, we propose a framework to develop a customized and smart medical mask system for the HCP individual as well as the HCP society. The proposed mask design process is consisted of three phases: (1) Three-dimensional (3D) face scanning to get individual face geometry for the mask customization, (2) Aerosol Jet Print (AJP) temperature/strain gauge sensors, and (3) wirelessly transmitting the sensor data in real-time.

The 3D scanning technology has been ubiquitous in the field of industrial manufacturing and others. Interesting studies have been pursued; for example, the accuracy of the 3D scanners in products' design process was analyzed [5]. Also, 3D scanned images from various modalities can form an image fusion to support medical surgery plan and evaluation [6].

There are several attempts to utilize the 3D face scanning idea into personalized masks design and fabrications. With the 3D traditional printing technology, Swennen et al. [7] demonstrated a 3D printed, reusable, and individualized 3D protective face mask. In support of Korean Air Force

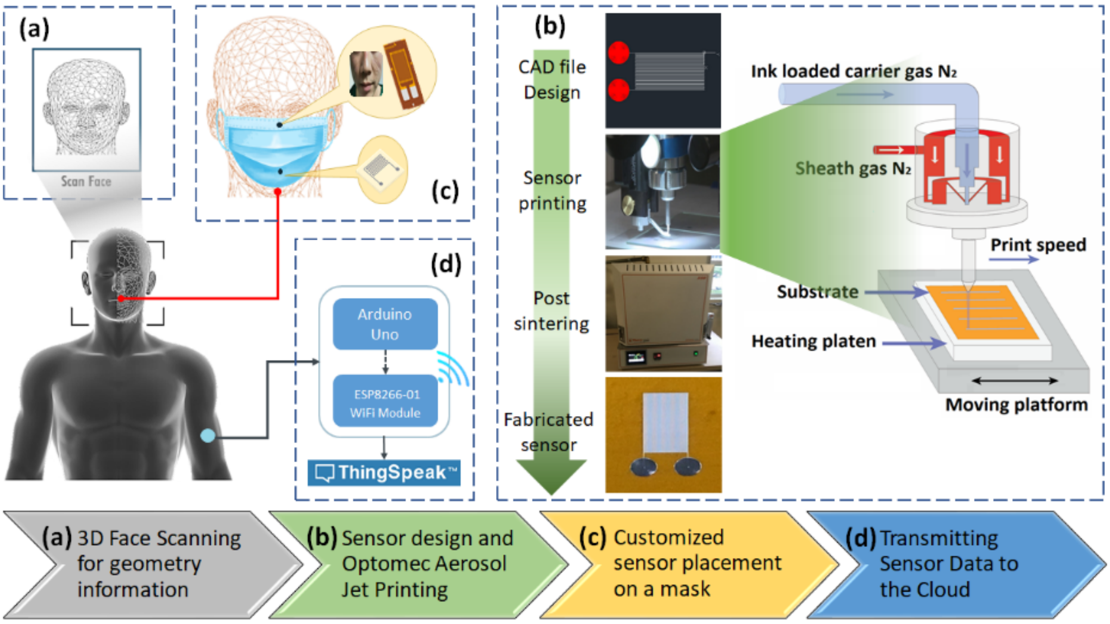


Figure 2 The customized smart mask system design process: (a) Attaining 3D face scanning information. Analyzing individual face geometric data to be used in sensors' design (b) Printing the customized sensors (temperature, strain) via the AJP technology

pilots, Lee [8] designed an oxygen mask shaped based on 3D facial characteristics ergonomically.

A customization 3D respiratory mask has been demonstrated using 495 facial scanned anthropometric databases with a machine learning approach developing a 3D parametric face model [9]. Their study was promising as face masks situate directly onto human reportorial systems such as nose and mouth.

Not a face mask, but Basra et al. [10] developed a non-invasive, portable respiratory sensor using a commercially available temperature sensor. The system measures the temperature difference between inhalation and exhalation phases of the respiratory cycle where an abnormal respiration rate can indicate a variety of pathological conditions.

Despite all attention and appreciation on the 3D face scanning technologies concerning human respiratory system monitoring, practical application development has not been prevalent in industrial manufacturing fields. One of the main reasons would be due to commercial sensors' design; it does not mean to be ergonomic in size, dimension, and flexibility.

3D printed sensors with various 3D printing techniques have been introduced in recent review papers. The sensing electronics utilization in the biomedical application has been emphasized, including temperature and strain gauge sensors [11]. The AJP is a relatively new 3D printing technology that allows made-to-order designs. Compared to traditional and other 3D printing techniques, the AJP is advantageous in fabricating flexible electronic sensors and devices in terms of design, costs, surfaces, and substrates [12]. As such, the sensors printed with AJP technology can be suitable for ergonomics and customized design application.

Continuous health monitoring and supervision are vital for those who are in vulnerable as well as frontline positions to fight with COVID-19. Our study objectives are to impart a design process and a prototype for the customized medical mask system that exploits the 3D face scanning and AJP technologies. The proposed system monitors subjects' physiological parameters transmitted from the printed sensors embedded in a mask in real-time. For example, if an abrupt and sudden change is detected in respiratory temperature, the subject may be suspected of adverse health conditions. Also, information transmitted from a strain sensor (placed on the mask's metal strip) can help analyze chronic force applied to the local face area. As in all, the suggested monitoring system enables to alarm medical professionals to take a rest or to advise further diagnosis on her/his pathological symptoms.

II. METHODOLOGY

Figure 2 shows the proposed system design process framework. The face is scanned in 3D to acquire geometric facial information. The 3D scanning data can be used in two phases: sensors' design and mask fabrication. For example, everyone has a unique local position and size of face parts (i.e., nose, mouth). Thus, sensors with customized shape and size can be designed and printed. Also, the data allows adaptively customized placement of sensors on the mask.

For the mask fabrication, as shown in Figure 3, design idea suggests placing the strain gauge near to the thin and flexible metal strip on the mask. And the temperature sensor is situated near to the nose and mouth where breathing air in/out. For feasibility test, layering two masks and embedded the sensors within the covers. For testing, a person is holding a set of a microcontroller to communicate with external servers.

A. Face 3D scan

Due to the recent COVID-19 pandemic, the market for personal protective equipment (PPE) has been disrupted. During peak time, the demand has been up to 100 times higher than usual. Lacking in resource availability, people started to find a way of designing DIY or personalized masks with various approaches. For example, a customer can order a personalized mask and a filter with his/her 3D facial scanning input using their mobile phone [13].

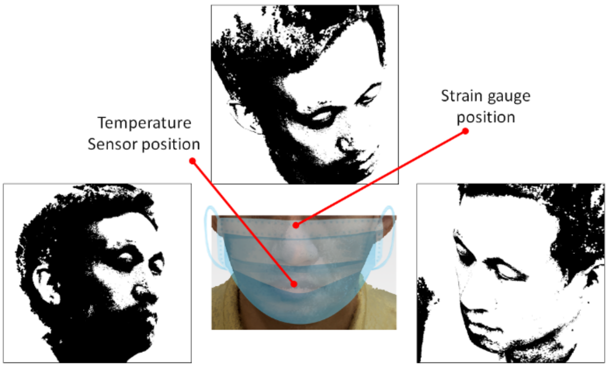


Figure 3 Face 3D scan examples with sensor position optimization. The 3D face scanning was performed with an iPhone app, "the Capture: 3D Scan Anything."

As shown in Figure 3, 3D facial scanning was carried out using a smartphone (iPhone11; Apple Inc., Cupertino, CA, USA; https://www.apple.com) and the Capture: 3D Scan Anything (Standard Cyborg, Inc., San Francisco, CA, USA; https://www.standardcyborg.com/), which was downloaded from the App Store. With the 3D scanning process, a usdg formatted file was obtained. The file can be converted and exported to commercial 3D design software such as SolidWorks for further 3D design customization.

B. Sensors design

When fabricating of printed electronics, substrates have played a significant role in shaping the physical, mechanical, and electrical features of the devices. The commonly used thin polymeric substrates include polyetherimide, polycarbonate, polyacrylate, polyethene, polyurethane, and PI [14, 15]. In comparison with the mentioned substrates, in this project, we use the PI as the substrate material for printing the sensing prototypes, as discussed above. Functional printing threads should be lined with high controllability and excellent uniformity, and hence, it can be fulfilled with morphology control and uniform control [16]. In this study, one of the inorganic metallic inks, Ag has been used as the conductive ink over the substrate, PI. Due to the promising material in the conductive ink that can be used in many electronic applications and still can conduct at oxide form, the Ag is one of the most commonly used functional metallic ink in the market [15].

The strain gauge sensor

The approach for designing the strain sensor illustrated in Figure 4 is to use semi-circle or semi-hemisphere as the cross-sectional area (A in Eq.1) shape, and 50 µm as the minimum width or diameter for each microchannel. Substrate material, polyimide (PI) is selected for fabricating such strain gauge sensors due to its flexibility, transparency, good surface face roughness, and combability to silver (Ag) ink [14]. As the diameter of the semi-circle is 50 µm, the radius (r) will be 25 µm. Thus, the cross-sectional area for the sensing prototype can be obtained from the equation:

$$A = \frac{\pi r^2}{2} \qquad (1)$$

To derive the semicircular dimension of the thread structure, we start from the average resistivity of the conductive ink (ρ)

$$\rho = 10\text{-}50 \times 10^{-8}\Omega m \qquad (2)$$
$$\approx 30 \times 10^{-8}\Omega m$$

The Eqs.1 and 2 can be combined with Eq. 3, the target resistance (R) for the strain gauge is 350 Ω; thus, the overall length of the trace ℓ can be calculated as shown in Eq. 4 with the following formulas:

$$R = \frac{\rho\ell}{A} = \frac{\rho\ell}{\frac{1}{2}\pi r^2} \qquad (3)$$

$$350\Omega = \frac{30 \times 10^{-8}\Omega m \times \ell}{\frac{1}{2}\pi(25\mu m)^2}$$

and

$$\ell = 1.145372 \approx 1.14\, m$$

As

$$\ell = 2n\,(L + \pi r_1) - \pi r_1 \qquad (4)$$

where $r_1 = 50\mu m$, n=50 is the total number of microchannels used in this framework, the length (L) of each microchannel can be calculated as L= $11{,}244\mu m$.

As in all, the resulting Serpentine pattern printed out to emulate a strain gauge that is repeated n number of times is illustrated in **Error! Reference source not found.**

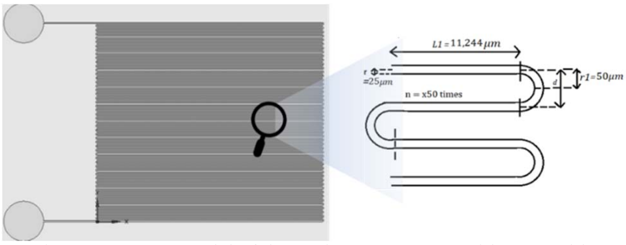


Figure 4 A CAD model of the strain gauge sensor with zoomed-in serpentine dimensions

The temperature sensor

The schematic representation of the designed temperature sensor is illustrated in Figure 5; materials used for electronics development are indicated. The printed sensing prototype can detect the body temperature of an individual accurately.

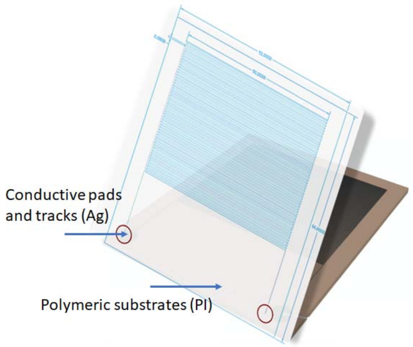


Figure 5 CAD design of the temperature sensor (Autodesk, AutoCAD) 2D dimension projection to 3D Design structure and dimensions with materials.

The resistance (R) of the ink and the total number of microchannels (n) used in this framework are 620 Ω and 100, respectively. The length (L) of each microchannel can be calculated with the Eqs. 3 and 4. It is thereby giving the length of each microchannel to be 10mm.

III. RESULTS AND DISCUSSION

Printed sensing prototype as shown in Figure 6, was developed by AJP technique.

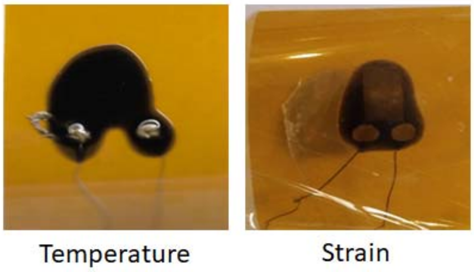


Figure 6 Example of printed sensors with Aerosol Jet printing

As shown in Figure 7, the experimental setup consists of an Arduino, a 100Ω resistor, 5V Vin, and the printed device. The 100Ω resistor value should be re-considered for each sensor unit as it controls analogue voltage ranges to the MCU.

For an example, assume that ADC value is read from the MCU with a value of 624 in Figure 8; then, the output voltage of the printed temperature sensor (Eq. 5) can be calculated:

$$Vout = \frac{Vin \times ADC\ value}{1023} = 3.05\text{V} \qquad (5)$$

Thereby, the resistance of the sensor (Eq. 6) can then be obtained by using the simple voltage divider network formula then substituting V_{out} into the formula:

$$Rsensor = R \times \left(\frac{Vin}{Vout} - 1\right) = 63.93\Omega \qquad (6)$$

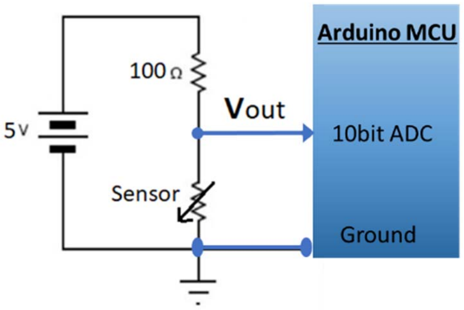
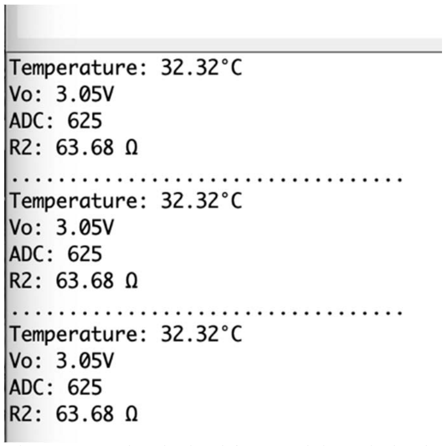


Figure 7 Sensor circuit schematic

The printed result from the flexible temperature sensor electronic was obtained and derived as illustrated below in Figure 6. The temperature was calculated based on the calibration.



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Temperature: 32.32°C
Vo: 3.05V
ADC: 625
R2: 63.68 Ω
.................................
Temperature: 32.32°C
Vo: 3.05V
ADC: 625
R2: 63.68 Ω
.................................
Temperature: 32.32°C
Vo: 3.05V
ADC: 625
R2: 63.68 Ω
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Figure 8 Results obtained from Arduino wirelessly

IV. CONCLUSION AND FUTURE PERSPECTIVES

In this study, we proposed a smart health monitoring system using a customized smart medical mask with Aerosol Jet 3D printing technology which drives low-cost and customization paradigm. The proposed system was motivated to support medical professionals who were working in the frontline to battle the COVID19 pandemic situation. Features to be noted on the proposed system include customization of a mask via 3D face geometric scanning, utilization of AJP technology for printing flexible electronic sensors (temperature, strain gauge), and monitoring of an individual's health conditions wirelessly in real-time. The derivation of sensors' design, materials used in this work, and implementation were also discussed. With a 3D scanned database, the proposed design process can be extended to various monitoring system development with customized sensors yeiling affordable system cost.

As a future work, system integration beginning from the 3D face scanning to data transmission should be investigated.

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