IoT Methods for Determining PPE Mask Fitness

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***Abstract*—The COVID-19 pandemic showed the importance of Personal Protective Equipment (PPE), which has been instrumental in providing efficient and effective protection against exposure to the virus for its users. The widespread use of face masks has highlighted the shortcomings of single-use PPE, in particular, the fit of a mask has a large impact on its effectiveness. The research presented in this paper focuses on automatically determining the fitness of masks on an individual with any face structure. The approach in this paper is to use IoT sensors attached to PPE masks in order to detect the tightness and fit of the mask. This approach was tested using three different types of commercially available masks and showed that it is feasible to detect their tightness and fit of them. This study concludes that IoT-based methods can be used effectively to improve the safety of PPE masks.**

I. Introduction

The aim of a mask is to protect the user from unwanted particles, pathogens, and viruses present in the air [1]. It is also one of the most important aspects of Personal Protective Equipment (PPE) used in various facilities such as Healthcare, Police/Military, Firefighters, etc. Due to the outbreak of COVID-19, various kinds of face masks are used for protection purposes. Reusable fabric masks, bandanas, Surgical masks, Dust masks, and respirators, are globally used by healthcare workers, the military, and now by the people to prevent the spread of coronavirus, generic viruses, and dust particles.

The shape and fit of a mask may alter as the body moves, making the environment infectious and the individual exposed to any type of infection. Research conducted by a researcher and his team, clearly shows that a mask will provide better protection if they are fully in contact with the skin. If the edges of the mask are in contact with the skin, it provides an efficient barrier for protection against any kind of contamination [2].

All of the above reasons exacerbated the shortcomings of traditional masks and highlighted the need for such technology that will detect or adjust the fitness of the mask.

The aim of the work presented in this paper is to investigate approaches for automatically determining the fitness of masks on any individual with any face structure. The key contributions of this paper are as follows: (i) Conducting a comprehensive literature review and market analysis to identify the shortcomings of current generation products and designs. (ii) To provide a solution for the automated mask fitting using different sensors and adjustable straps for the user. (iii) Testing the proposed method with 3 different most general used masks. (iv) Generating the data and comparing the results.

The remainder of the paper is as follows. Section II reviews the literature. Section III describes the design and implementation of the artefact. Section IV evaluates the artefacts and discusses it. Section V discusses and concludes the paper.

II. Literature Review

A. Introduction to PPE

Persistent use of protective measures such as masks can lead to an increase in CO2 intake or re-breathing, which can affect human well-being [3], [4]. In a study conducted by Wei Jiang, Sumit Majumder and team, IoT/sensors can also be used for detecting SARS-CoV-2 in symptomatic individuals by analyzing body temperatures with the help of thermistors [5]. These technologies when implemented with masks have an advantage over surgical/normal masks because of their dockable nature, i.e., being reusable and sustainable [6] and hence are called Smart Masks. Similarly, a few other smart masks have been researched that are made up of different sensors that record and adapt according to the readings. For instance, an experiment conducted with the help of a radio frequency (RF) harmonic transponder, can detect any kind of virus transmitted by the person wearing it. All of these help in the easy and accurate detection of viral transmissions [7], [8].

B. Trends in PPE

The structural design of the PPE changes every year with the constant technological advancement and with a vision of making it more compatible, easy to use, sustainable and ‘Smart’ meaning providing extra features other than just filtering the air. Smart PPE is built on the “Sense”, “Think” and “Act” model, in which depending on the nature of the industry, the application and design for PPE vary but the track of human participation, the core component of all smart PPE is kept constant [9].

One of the main issues that were observed in the Healthcare industry is cross-contamination due to improper removal and fitting of masks and gowns. In response to this PPE must need to be used with air filtration [10]. In recent years, a rise in the use of smart solutions for healthcare procedures has been seen. ‘Negative Pressure Cooling vest’, against the issue of Hyperthermia during medical procedures. Other than this, the’Heat Detection Method’ and ‘Behavioural Cooling Strategies’ are also proven to be effective against Hyperthermia [11].

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‘Google Glass’ is considered one of the smart solutions used by front-line workers, mainly dealing with bio-hazards and assessing any kind of threats. Another project, called ‘Smart-Pro’, that came out in 2014, is a high-technology protective vest developed for an individual’s safety and security. It is a smart vest that not only collects data from the person wearing it but also provides ballistic and stabbing protection [11].

C. Issues With PPE

Despite being quite beneficial and productive, PPE has some negative implications. These issues can be considered small if compared to the benefits of PPE as there is no other replacement for it yet [11], [12]. The most common problems associated with PPE kits are as follows.

- Excessive sweating 100% [11], [12].
- Fogging of goggles, spectacles, or face shields 88% [11], [12].
- Suffocation 83% [11], [12].
- Breathlessness 61% [11], [12].
- Fatigue 75% [11], [12].
- Headache due to prolonged use 28% [11], [12].
- Pressure marks on the skin at one or more areas on repeated use 19% [11], [12].

This is the grey area of PPE that can be dealt with by using modern technology. In order to make the PPE act according to the ‘sense, think and act’ model, progress should be made on the operating conditions in the early design stage as most of the time, requirements are overlooked when integrating the smartness to PPE [13]–[15].

D. Current State of new technology of Masks

Although N95 masks have proven to be best in use during COVID times [16]. The new technology in masks has been evolving for quite some time now and sped up during the COVID in order to produce better protection for the public. Researchers have undertaken several approaches and methods to try and build such a mask that can not only stop the spread of particles but can also minimize breathing issues, purify the air (adjusting according to the air quality in the surrounding environment) and be less complex in its design for more comfort. There are some masks that are already available in the market for different conditions, such as running masks, cycling masks, and anti-smoke masks. All of these masks have some major concerns in the UX/UI department, which is repeated over and over again irrespective of the company manufacturing it [11], [17].

Such issues that are related to the design of the smart masks, can be caused by a list of factors which may include issues due to the form factor, low energy consumption as well as a safety measure like avoiding physical injury. There already are a lot of technologies that are focusing on sensing, wireless communication, and nanotechnology to successfully construct a mask but choosing its physical structure and outer design using the appropriate sensors and other things, requires critical understanding [18].

Product	Project Hazel	CX-9	LG Wearable	Forcit	Air Pop	FaceBit
Ventilation	✓	✓	✓	N/A	N/A	N/A
Voice Modulation	✓	✓	✓	✓	N/A	N/A
Heavy	N/A	✓	✓	✓	✓	✓
Washable	N/A	N/A	N/A	✓	N/A	N/A
Sweat/Water Resistant	N/A	N/A	N/A	N/A	N/A	N/A
Data / Sensor fusion/ Sensing	N/A	N/A	N/A	N/A	✓	✓
Nano Technologies	N/A	N/A	N/A	N/A	N/A	✓
Automated Fitting	N/A	N/A	N/A	N/A	N/A	N/A
Notifying Filters	N/A	N/A	N/A	✓	✓	✓
Heavy Breathing/ Running	✓	✓	✓	N/A	N/A	✓
Cross Contamination	N/A	✓	✓	✓	✓	✓
Education Compliance	N/A	N/A	N/A	N/A	N/A	N/A
Comfort	✓	✓	✓	✓	✓	✓
Style/Fashion	✓	✓	✓	✓	✓	N/A

Table I
COMPARISON OF SMART-MASKS, THEIR SENSORS, MAIN FOCUS AND CHALLENGES

All the masks that show some ”Sense”, ”Think” and ”Act” behaviour are shown in Table I. The table compares the main components and behaviours of the masks with each other. All masks are comfortable. Project Hazel does not provide cross-contamination but is lighter than other masks whereas Face-Bit is not stylish. Although For-cit, Air Pop and Face-Bit are notifying for filter change which is another factor to provide more protection to the user none of them was focusing on adjusting the fitness or tightness. The other crucial components are filtration, fitting, sensor fusion and battery compliance. None of them can be found in any of the masks. Some other masks that are currently under construction, focus on Sensing and Real-Time AI functioning but do not focus on Design and Ventilation [18]. To find the solution for adjusting the mask fitness and tightness there is a need to use some sensors and actuators that can sense the resilience between the mask and the skin of the user and adjust the mask accordingly. This will obviously be distinct and specific to each person depending upon their health and surroundings [19].

III. DESIGN & EXPERIMENT SETUP

In this section, we will present our proposed smart mask depicted in Figure 1 and will explain its components and work-flow. The proposed mask consists of two LDR sensors, one temperature-humidity DHT11 sensor, and a microcontroller with an adjustable strap.

Different sets of masks have different structures which will perform differently when sensors are placed inside the mask. For LDR sensors that are used to sense the intensity of light inside the mask, it is necessary to cover the entire area of the mask as well as the most vulnerable areas to air/light. So, sensors are placed at the two ends of the masks. For the DHT11 sensor which will be used to sense the temperature and humidity inside the mask will be positioned in front of the mouth at the centre of the mask. This is because the values of the temperature and humidity vary at different positions inside the mask as well as if it is in contact with the skin. So, In order to lower the variations sensor is retrofitted in the middle of the mask which will always be at some distance from the skin of the user. Also, the values will mainly be affected if the user breaths in/out and the sensor catches it straight away. Figure 2 illustrates the set-up of sensors inside the mask.

Arduino UNO R3 is the microprocessor used to program the sensors listed above. Data will be collected through the sensor with the help if Arduino and will be saved in the format of CSV file, serial monitor of the microprocessor will display the data while the serial plotter will plot the data.

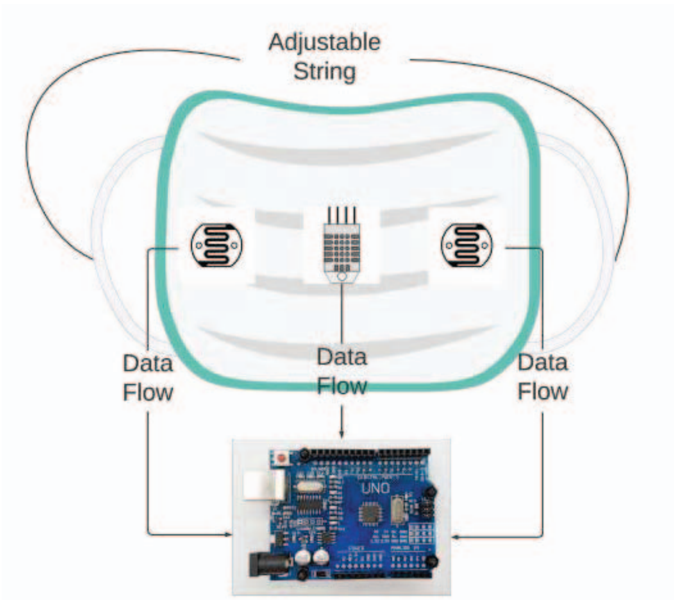


Figure 1. Prototype of the Smart Mask

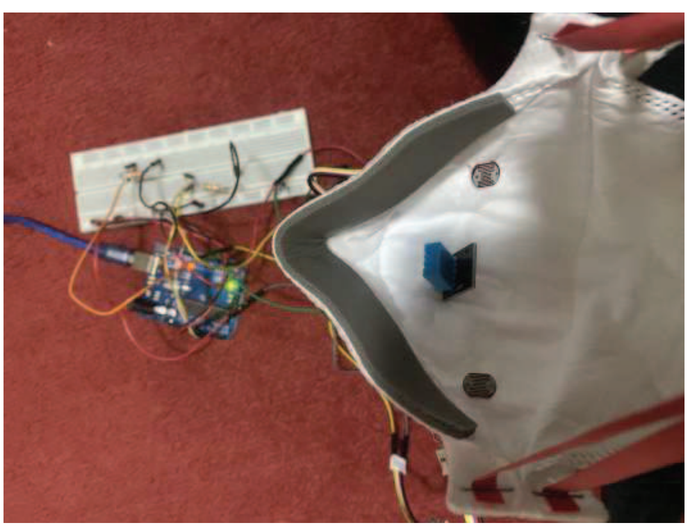


Figure 2. Set up of sensors inside the mask

IV. Experimental Evaluation

This section presents an experimental evaluation to determine the exceptional mask fitting using proposed smart mask as shown in Figure 3 with adjustable straps using three different scenarios with set up described in : (i) Correlation between the LDR sensor intensity with the length of the Adjustable strap. (ii) Variation of temperature and humidity inside the mask (iii) Variation of LDR sensor Intensity by changing the strap length of either side of mask.

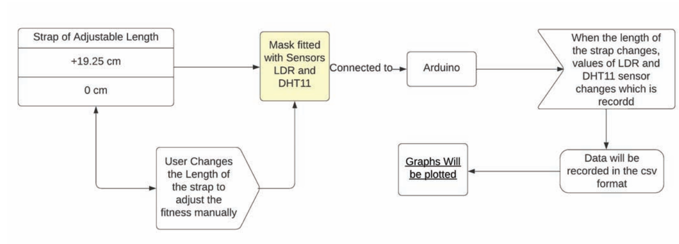


Figure 3. Design and Plotting of the Data

A. Correlation between the LDR Sensors and the Length of the Adjustable Strap of Different Masks

In this section, the aim is to find the perfect fit of the mask by comparing the intensity of the LDR sensor of all three masks. The intensity of light caught by the sensors will depict how close is the mask to the user's face.

Figure 4 illustrates the setup worn by the user with two LDR sensors of the same type are retrofitted to two ends of the mask inside. Furthermore, an adjustable strap of length 19.25 cm is tied to the ends of the strings of the mask. The sensors are then connected to the Arduino UNO microprocessor through jumper wires.

The outcomes of the experiment are recorded by performing it 10 times with the variation in length of the strap. Initially, the length is kept at 19.25cm, resulting in intensities of 8 and 9 recorded by the right and left LDR sensors respectively. Then the length of strap is decreased by 2.25 cm and the readings of the sensors were taken again, which resulted in intensity of 6 and 8 respectively. Similarly, the experiment is then performed 8 more times till the length of strap is decreased to 0cm.

The experiment is conducted on three masks with varying material, in order to get unbiased results. The type of masks used are:

- Surgical Mask — Polyester
- Fabric Mask — Cotton
- KN95 Mask — Polypropylene Plastic Polymer

1) Observations for Surgical Mask: Table II contains the readings of LDR sensor intensity with surgical mask.

Figure 5a displays that the intensity of light measured by LDR sensors inside the surgical mask is directly proportional to the length of the strap, which implies decreasing the

Figure 4. Setup worn by user

length the distance between the mask and the user's face also decreases. When the length of the strap reaches 0 cm, the reading of both sensors falls to intensity 1, indicating that the mask is closest to the face without any gap. At this point, the face mask is tight according to the user.

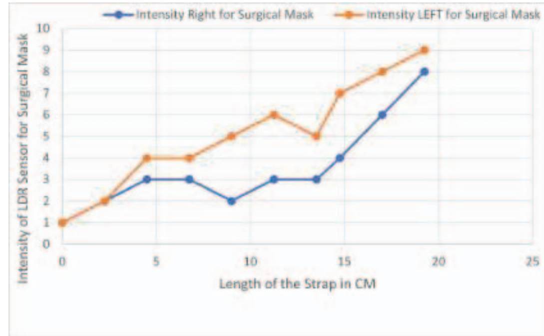
Length of Strap in cm	User's Tightness	Intensity Right	Intensity LEFT
19.25	LOOSE	8	9
17	LOOSE	6	8
14.75	SLIGHTLY LOOSE	4	7
13.5	SLIGHTLY LOOSE	3	5
11.25	SLIGHTLY NORMAL	3	6
9	SLIGHTLY NORMAL	2	5
6.75	NORMAL	3	4
4.5	NORMAL	3	4
2.25	TIGHT	2	2
0	TIGHT	1	1

Table II
READINGS OF THE EXPERIMENT OF LDR SENSORS WITH SURGICAL MASK

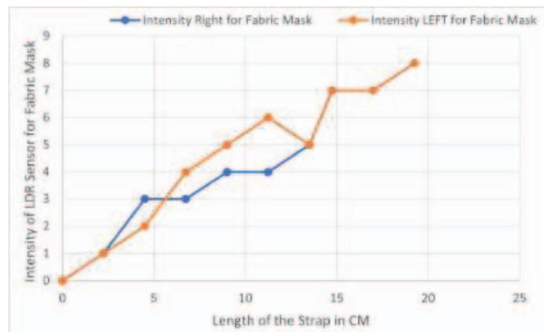
2) Observations for Fabric Mask: Figure 5b displays the intensity of light measured by LDR sensors inside the fabric mask is directly proportional to the length of the strap, which provides a similar result as of surgical mask. When the length of the strap reaches 0 cm, the reading of both sensors falls to intensity 0, indicating that the mask could be tight as per the user.

3) Observations for KN95 Mask: Table III contains the readings of LDR sensor intensity with KN95 mask.

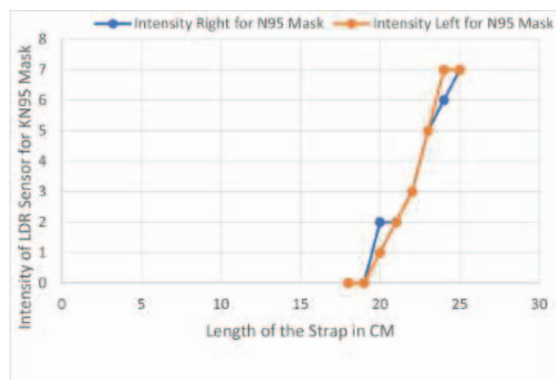
Figure 5c displays the intensity of light measured by LDR sensors inside the KN95 mask is directly proportional to the length of the strap, which implies on decreasing the length the



(a)



(b)



(c)

Figure 5. Variation of Intensity with the length of Strap with (a) Surgical Mask, (b) Fabric Mask, (c) KN95 Mask

distance between the mask and user's face also decreases. It should be noted that in KN95 mask, the length of the strap varies from 18cm to 25cm, whereas for surgical and fabric masks length ranges from 0cm to 19.25 cm. Because of the different structures of N95 masks, as the length of the strap reaches at 19 cm, the reading of both sensors falls to intensity 0, indicating that the mask could be tight as per the user and closest to the face. Furthermore, when the length of the strap of this mask is decreased by a further 1cm, the intensity remains 0 but the mask feels tighter according to the user.

By analysing the results of all three experiments, it was concluded that intensity of light decreases with a decrease in the strap's length in all scenarios. It was also found that KN95 masks were superior to the other two masks, as the minimum value of intensity was found when length was shortened to 0 in surgical and cloth masks, whereas in KN95 masks it was different. The intensity 0 in N95 masks was calculated when the length was 18cm, which means these masks need not to tighten much to gain better results.

It should be duly noted that the intensity of Light measured depends on various other factors, such as the quality/material, structure (in KN95) of the mask.

Length of Strap in cm	User's Tightness	Left N95	Right N95
25	LOOSE	7	7
24	LOOSE	7	6
23	SLIGHTLY LOOSE	5	5
22	SLIGHTLY NORMAL	3	3
21	NORMAL	2	2
20	NORMAL	1	2
19	TIGHT	0	0
18	VERY TIGHT	0	0

Table III
READINGS OF THE EXPERIMENT OF LDR SENSORS WITH KN95 MASK

Length of Strap in cm	User's Tightness	TEMP
19.25	LOOSE	25
17	LOOSE	27
14.75	SLIGHTLY LOOSE	28
13.5	SLIGHTLY LOOSE	29
11.25	SLIGHTLY NORMAL	31
9	SLIGHTLY NORMAL	32
6.75	NORMAL	33
4.5	NORMAL	35
2.25	TIGHT	35
0	TIGHT	36

Table IV
READINGS OF THE TEMPERATURE OF DHT11 SENSOR WITH SURGICAL MASK

B. Variation of Temperature and Humidity with length of strap

The aim is to find temperature and humidity inside the mask with the variation of length of adjustable strap with the same setup in Section III.

This experiment is conducted on two masks with varying materials, in order to get raw calculated results. The type of masks used are:

- Surgical Mask — Polyester
- KN95 Mask — Polypropylene Plastic Polymer

1) Variation of Temperature with Surgical Mask: The set of readings recorded for the temperature sensor are displayed in Table IV

From the Table IV, variation of Temperature is plotted onto a graph in Figure 6. Length is varied at X-axis and Temperature is recorded at Y-axis.

As seen in the Figure 6, the temperature measured by DHT11 sensor is inversely proportional to length of the strap, which means that on decreasing the length of the strap, the distance between the mask and user's mouth also decreases. When the length is reduced to 0 cm, the reading of the sensor reaches to 36 degrees, indicating that the user might feel the mask is tight and is close to face.

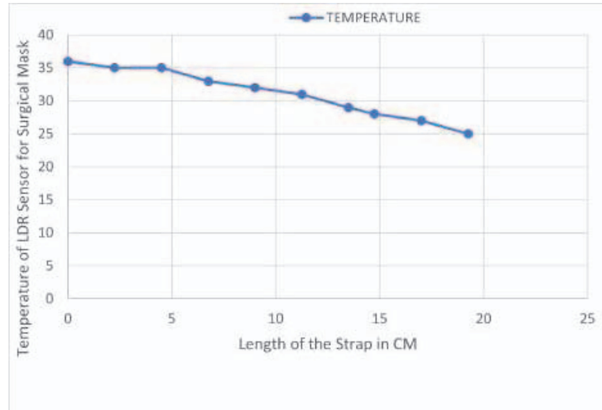


Figure 6. Variation of Temperature in Celsius inside the surgical mask

2) Variation of Humidity with Surgical Mask: Figure 7 exhibits a similar trend of variation with the temperature as when the length reaches 0cm, humidity increases to 90rh, indicating the mask is close to the respiratory orifices.

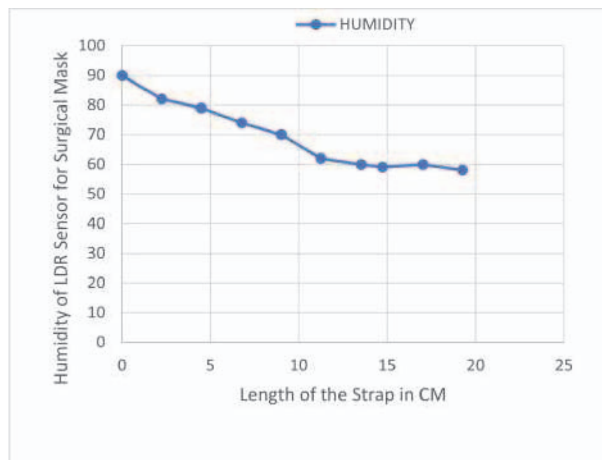


Figure 7. Variation of Humidity inside the surgical mask

3) Variation of Temperature with KN95 Mask: The set of readings recorded for the temperature sensor is displayed in Table V, variation of temperature is plotted onto a graph in Figure 8. Length is varied at X-axis and temperature is recorded at Y-axis. Figure 8 exhibits a similar trend of variation of temperature as in surgical masks. But a dramatic increase in temperature is observed when the length of the strap is reduced. Similarly, Figure 9 exhibits a similar trend of variation of humidity as in surgical masks. Like temperature, humidity is strictly increasing when the length is shortened. On carefully analyzing the results of both the experiments, it was deduced that both temperature and humidity in a mask increase with a decrease in the strap's length. It was found that in KN95 masks due to the restrictive flow of air, temperature and humidity were increasing rapidly when the

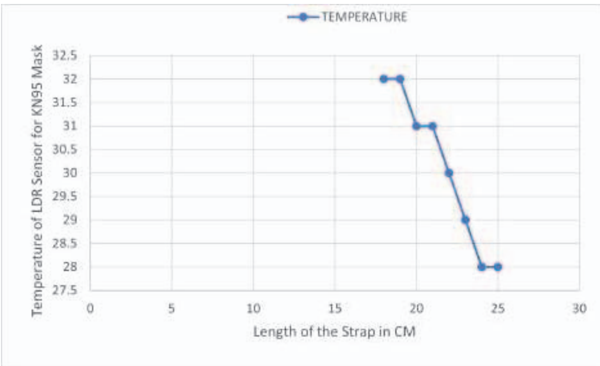


Figure 8. Variation of Temperature in Celsius inside the KN95 mask

strap was tightened, making it better than the surgical mask for protection. Moreover, it should be considered that the temperature and humidity measured depends on other different factors, for instance, the quality/material and the structure (in KN95) of the mask.

Length of Strings	User's Tightness	Temperature N95	Humidity N95
25	LOOSE	28	78
24	LOOSE	28	80
23	SLIGHTLY LOOSE	29	83
22	SLIGHTLY NORMAL	30	85
21	NORMAL	31	89
20	NORMAL	31	90
19	TIGHT	34	92
18	VERY TIGHT	37	95

Table V
READINGS OF THE TEMPERATURE AND HUMIDITY OF DHT11 SENSOR WITH KN95 MASK

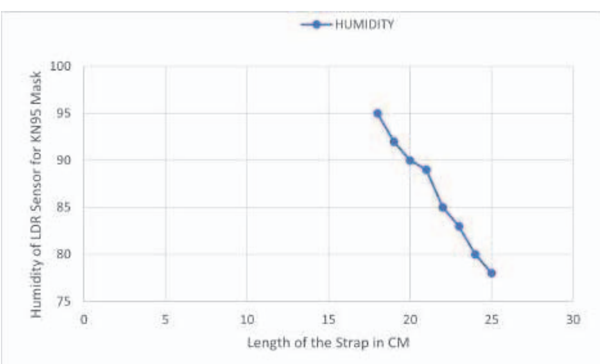


Figure 9. Variation of Humidity inside the KN95 mask

C. Variation of LDR sensor Intensity by changing the strap length of either side of Surgical mask

The aim is to find the variation of intensity of either side of the LDR sensor by changing the length of the string on the opposite side of the sensor. The setup is similar to that in Section IV-A with the KN95 mask. The set of readings recorded for the LDR sensors attached to the KN95 mask are displayed in Table VI. From Table VI, variation of Intensity of LDR sensors is plotted onto a graph in Figure 10. Length is varied at X-axis and Intensity is recorded at Y-axis.

Length of String in cm	User's Tightness	LDR Left	LDR Right
25	LOOSE	0	1
24	LOOSE	1	2
23	SLIGHTLY LOOSE	2	3
22	SLIGHTLY NORMAL	2	5
21	NORMAL	4	7
20	NORMAL	5	10
19	TIGHT	7	12

Table VI
VARIATION OF RIGHT LDR SENSOR BY CHANGING LENGTH OF KN95 MASK

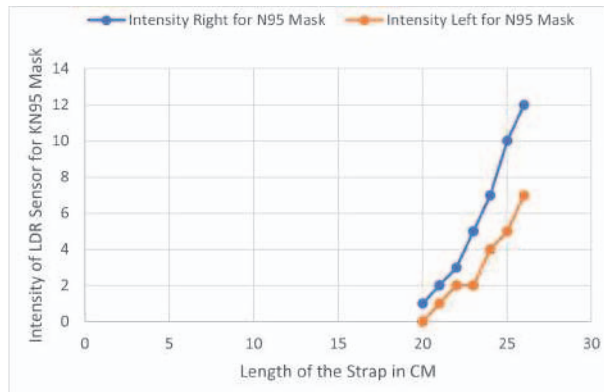


Figure 10. Variation of Right LDR intensity by changing the length of the right side of KN95 mask

V. DISCUSSION

Data comparison for all three different masks of LDR light Intensity is shown in Figure 5. For both surgical and fabric masks intensity of light decreases gradually as the length of the strap is decreased. Where in case of the KN95 mask because of its different structure/shape, tightness, as well as the length of the strap, it varies differently as explained in Section IV. Similar behavior is observed in all three masks as the value of light intensity of LDR sensor were decreasing when the length of strap is changing. On the basis of how the intensity decreased based on the length of strap N95 mask is chosen to perform another set of experiments.

The KN95 mask is then chosen over another set of masks and retrofitted with DHT11 sensor. The mask is worn by the user as shown in Figure 4 for 2 min while performing some activities like speaking, walking, etc. The inner side of the mask is shown in Figure 2. While performing the experiments, positioning of the sensors was also taken care of and adjusted as needed to minimize bias in the experiments as it was observed that if sensors were placed in any position other than the one shown in Figure 2 the readings may be inaccurate. So, for the position of DHT11 sensor, the readings of LDR sensors were taken at different positions inside the mask, and the best position where the intensity comes out to be zero with respect to the length of the strap was chosen.

After the mask was worn by the user the data collected while performing activities are plotted in Figure 11. A gradual increase in the temperature was observed from the point when the mask is worn till it was removed. The orange line indicates an increase in temperature. For humidity, a sharp increase was observed in the beginning and which stabilized after a few seconds of use, indicated by the blue line. Both LDR sensors on the left and right of the mask exhibited similar behavior. The movement caused while speaking shifted the mask away from the position of best fit which caused an increase in the intensity monitored by the LDR sensors which can be observed by the grey and yellow lines in Figure 11.

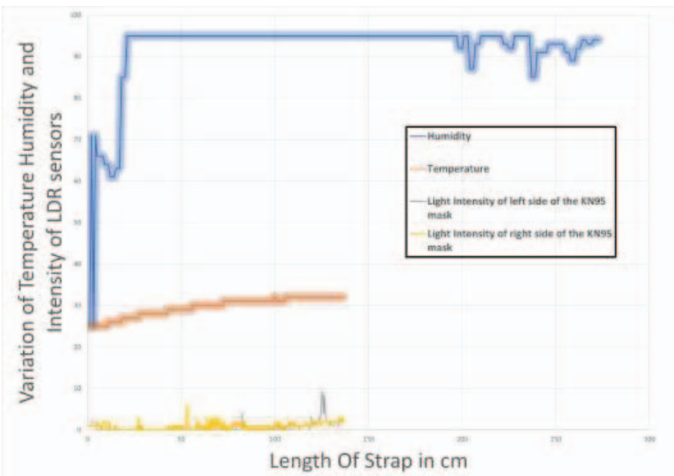


Figure 11. Data Collected after the mask is worn for 2 minutes

VI. Conclusions & Future Work

The perfect fit of the mask on the skin provides better protection against contamination, it will boost the efficiency of the face mask. The mask's operation will be depending on the intensity of light since sensors attached to the mask will detect light breaches. The presence of light indicates that the mask is not properly fitted to the user's face. The mask is also equipped with a temperature and humidity sensor, which detects differences between when the mask is loose, indicating light within the mask, and when the mask is tight (perfect fit), indicating no light inside.

The future goals of this report are to work on automating the mask adjustment so that it can get the greatest fit. To notify the user if the mask's optimal fit position is lost. To make the mask reusable by cleaning the masks. Monitor the user's health using temperature and humidity data collected.

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