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IMAGE-BASED WEB APPLICATION FOR RESPIRATOR SIZING: CONTACTLESS MASK-FITTING DURING A PANDEMIC

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ABSTRACT

At the beginning of the COVID-19 pandemic, many hospitals and healthcare institutions lacked an adequate supply of masks and other personal protective equipment. Moreover, protocols that were in place to ensure healthcare workers had appropriately sized masks consumed precious time and resources. Any determination of a user's correct respirator size demanded an in-person assessment and had the potential to waste multiple respirators. Here we introduce IBARS (Image-based Application for Respirator Sizing), a novel tool which provides respirator size recommendations based on a facial image and basic user demographics. This solution obviates the need for an in-person assessment, providing an accurate size recommendation within seconds. The application has the potential to reduce time-per-worker respirator fitting, reduce overall respirator usage, and increase safety by providing hospitals with a non-contact option for sizing. Furthermore, future applications may assist healthcare institutions optimize supply chains by providing rapid assessments and re-assessments of appropriate respirator sizes used by their workers. Early testing indicated accuracy of 71.3% for the software (N=16), and further testing is underway at Houston Methodist Hospital.

Keywords: PPE, N95, fit-test, facial recognition, NIOSH, mask sizing

NOMENCLATURE

PPE	Personal Protective Equipment
FFE	Fitted Filtration Efficiency
NIOSH	National Institute of Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
IBARS	Image-Based Application for Respirator Sizing
API	Application Programming Interface
CDC	Center for Disease Control

1. INTRODUCTION

A critical problem at the core of the COVID-19 pandemic, especially during the first few waves, was the shortage of personal protective equipment (PPE), such as masks, gowns, and gloves. The vast shortage was an international problem that put many health care workers at higher risk of infection and added to the overall transmission rate. One of the most limited and needed resources was the N95 respirator mask, which is a specialized face mask designed to filter out 95% of aerosolized infectious particles.

The Center for Disease Control (CDC) published guidelines for alternatives to N95 respirators due to limited supply, such as restricting usage unless absolutely necessary, mask recycling, and utilizing other physical barriers such as plastic visors [1]. Research on ways to sterilize respirators for re-use has been recently conducted or re-visited during the pandemic as well, such as ultraviolet germicidal irradiation (UVGI) [2], but little has been done to address the N95 wastage that occurs in the fit-testing process.

The National Institute for Occupational Safety and Health requires that every user be properly fit-tested before using a workplace respirator, including an N95 mask. Fit-testing checks the seal between a respirator's facepiece and the user's face to ensure that contaminated air cannot leak pass through [3]. A recent study showed that respirators of the wrong size could have decreased performance, down to 90-95% fitted filtration efficiency (FFE) [4].

Although mandated by NIOSH, fit-testing can provide numerous challenges for healthcare institutions and their workers. A typical fit test takes 15-20 minutes, meaning even a trained and experienced fit-tester can only complete about 3 fit-tests per hour (about 120 per week). One study found that 1295 healthcare workers were fit tested by four fit test providers over a 30-month period [5]. Additional staff may also be on-site to assist with record-keeping and logistics. Lastly, the current system for mask-fitting often wastes respirators. Certain protocols require a new mask to be used each time a size fails to fit correctly, so many N95 respirators are worn once and thrown away during fit-testing. In fact, initial fit pass rates vary between 40 and 90%. Additionally, the US Occupational Safety and Health Administration (OSHA) recommends annual fit testing, as the fit test pass rates are estimated to decrease from 90% to 80 % and 75% over 1 and 2 years respectively due to weight changes and their subsequent effect on facial dimensions [4].

At the start of the COVID-19 pandemic, a combination of N95 mask shortages and limited fit-testing availability forced hospital systems to reserve OSHA-mandated fit-testing only for the highest-risk health care workers, and people outside of health care had practically no access at all to N95 masks. Nearly two years later, the N95 shortage has been resolved in some areas, but fit-testing is still a resource- and time-intensive process. Therefore, a need exists to minimize the number of masks and the amount of time spent during an N95 fit-test to ensure that all patient-facing health care workers receive timely fit-testing while maintaining as many N95 respirators as possible for health care institutions and the public in general. Here, we describe a web-based solution that makes an accurate N95 size recommendation from a facial photo, expediting the fit-testing process and sparing masks that are tried on once and thrown away that are not the correct size.

2. MATERIALS AND METHODS

To make the process of mask-fitting more efficient and safe for healthcare institutions and their employees, a web-based application was designed using Python to replace current mask fitting protocols. This Image-based Application for Respirator Sizing (IBARS) accepts a facial photo from the user, as well as basic demographic information to standardize the calculation, and outputs the most likely respirator size for the user.

2.2 Respirator Fit Algorithm

The Python-based application first identifies key facial landmarks from an uploaded image. These landmarks, identified by Google CloudVision API, are used to measure facial height and width in pixels. Because pixel count is dependent on factors such as camera resolution and depth of field, a facial dimension that has low variance was necessary to

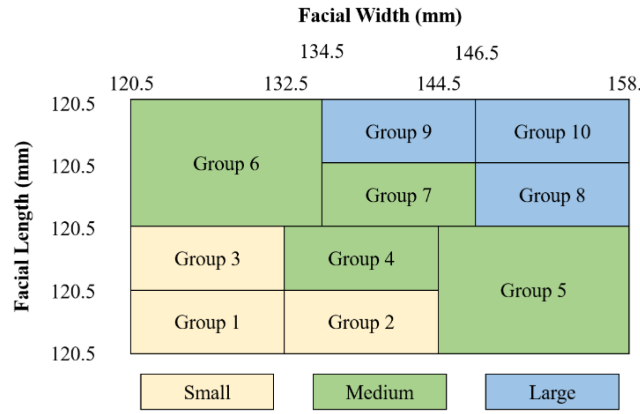


FIGURE 1: NIOSH BIVARIATE PANEL

use as a reference to convert pixel distances to actual distances. Inter-pupillary (IP) distance, defined as the straight-line distance between the center of the left pupil to the center of the right pupil, was used as such reference because this measure is less variant than other facial geometry, especially within a given age range, sex, and race [6]. To account for between-group variation, the application prompts the user for this demographic information.

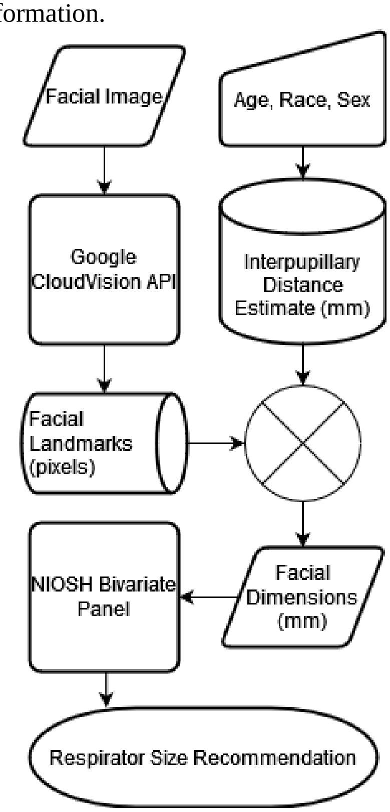
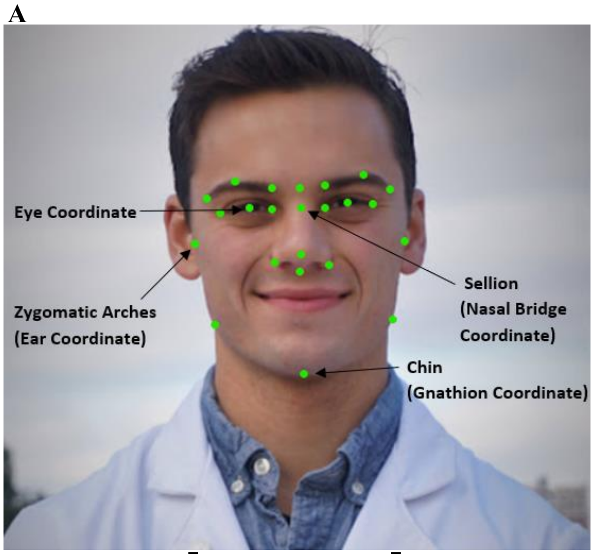


FIGURE 2: IBARS ALGORITHM

After IBARS measures the height and width of the face in the image, those dimensions are compared to the NIOSH bivariate panel for N95 mask sizing, which uses facial height and width as its only parameters (Figure 1). For the sake of the panel, facial width is defined as the distance between the zygomatic arches, and facial length is defined as the distance from chin to sellion (the deep point superior to the nose) [7]. These two dimensions place a face into one of ten groups. These groups cluster into small, medium, and large respirator sizes. IBARS reports this size to the user.

2.3 Example of Use

A



B

Age?	(A) Under 50, (B) > 50 years old
Race?	(A) White, (B) Black, (C) Asian, (D) Hispanic, (E) Indian
Sex?	(A) Male, (B) Female

C

X_LeftEye: 153.5995	X_LeftEar: 115.9486	X_NasalBridge: 182.5443
Y_LeftEye: 112.7022	Y_LeftEar: 130.6940	Y_NasalBridge: 110.4070
X_RightEye: 211.2995	X_RightEar: 247.7669	X_Gnathion: 182.0404
Y_RightEye: 109.6474	Y_RightEar: 128.0564	Y_Gnathion: 207.0305
IP distance: 62 mm (assumed) 57.7808 pixels	**Facial width: 141.4720 mm**	**Facial height: 103.6804 mm**

D

NIOSH Respirator Category = 2	**Size: Small**

FIGURE 3: (A) GOOGLE CLOUDVISION API IDENTIFIES LANDMARKS (GREEN DOTS) FROM PHOTO INPUT, (B) USER INPUTS DEMOGRAPHIC INFORMATION, (C) LANDMARK COORDINATES ARE SCALED AND CONVERTED TO FACIAL DIMENSIONS, (D) DIMENSIONS COMPARED TO NIOSH PANEL FOR RESPIRATOR CATEGORY; RECOMMENDED SIZE IS OUTPUT

2.4 Testing

The accuracy of IBARS was first assessed with a preliminary validation study of 16 community volunteers. A larger, IRB-approved follow-on validation and software improvement study is currently in process. In this study, hospital employee facial images are inputted into IBARS, and the output size recommendation is compared to their known mask size. The primary endpoint of that study is the proportion of IBARS results that match fit-test-confirmed N95 sizes.

3. RESULTS AND DISCUSSION

A study in April 2020 was conducted using images, demographic information (race, age, and sex), and fit-test-confirmed mask sizes from 16 community volunteers who work in health care settings (Figure 4). All participants reported respirators made by 3M, and models included 1860 and 1870+. The reported sizes were small, medium or regular, and large.

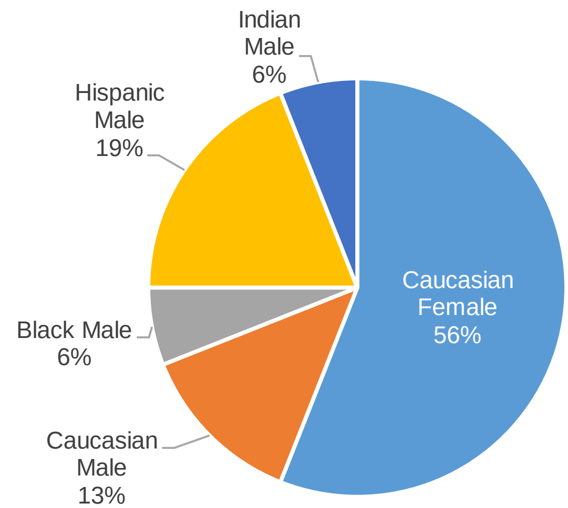


FIGURE 4: DEMOGRAPHIC DATA OF VOLUNTEERS IN INITIAL TESTING STUDY

A population proportion estimate derived from the results of the 16 volunteers was used to estimate the accuracy of the software. With a confidence level of 95% and scaled to a population of at least 10,000, this validation study estimates software accuracy of at least 71.3%. All females reported small respirator sizes compared to our algorithm's prediction of seven small sizes, one medium, and one in which the participants face was "too small to measure." Our algorithm accurately predicted the sizes from other demographics though it could not reliably predict the Indian male participant's respirator size due to challenges with photo resolution, angle, and obscurities in the image (Table 1).

Demographic	Accuracy (%)	Sample Size
Caucasian Female	78	9
Caucasian Male	100	2
Hispanic Male	100	3
Black Male	100	1
Indian Male	Inconclusive	1

TABLE 1: ACCURACY OF ALGORITHM BY RACE AND SEX

With promising results from the preliminary study, a larger follow-on study was initiated at Houston Methodist Hospital in the Texas Medical Center (IRB approval received on 9/9/21).

This study requests hospital employees with recent N95 fit-tests to submit facial photos that can be used to train the software and further validate the model. This is an on-going study.

The application has several limitations in its current form. Most significant of these is the need for users to include demographic information to account for variation in inter-pupillary distance between groups depending on their race, age, and sex. Within-group variation of inter-pupillary distance is reduced, but not eliminated, by this approach. Another limitation is reduced accuracy on faces with facial hair. Google Cloud Vision API does not accurately identify essential facial landmarks beneath beards, especially the location of the chin. However, proper N95 use does not permit long facial hair along the jawline or chin, so this inaccuracy should not affect a user who is undergoing NIOSH fit testing.

The application's baseline accuracy suggests many opportunities moving forward with continued software refinement. With a large enough data set, the model's accuracy can improve through machine learning techniques such as image classification or convolutional neural networks. This may also eliminate the need for demographic input. Furthermore, the model can expand to accommodate N95 masks from a wide variety of manufacturers, many of which have size conventions that vary from the traditional small-medium-large trichotomy.

4. CONCLUSION

The shortage of N95 respirators early in the COVID-19 pandemic shined a light on the inefficiency and waste in the respirator fit-testing process. While respirators are no longer as scarce as they were in early 2020, the application described here presents an opportunity for health care systems to reduce the time and respirators spent on fit-testing with a pre-test size recommendation. This application was originally designed to meet a need for contactless mask fitting in health care, but it can expand in scope with minimal modification to support PPE inventory planning and any industrial setting that is compliant with the NIOSH fit-testing process.

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