Naqaab: Towards health sensing and persuasion via masks

Rishiraj Adhikary Indian Institute of Technology (IIT), Gandhinagar Gujarat, India rishiraj.a@iitgn.ac.in Tanmay Srivastava Bharati Vidyapeeth's College of Engineering, Delhi Delhi, India srivastava.tanmay111@gmail.com Prerna Khanna Bharati Vidyapeeth's College of Engineering, Delhi Delhi, India prerna.khanna97@gmail.com

Aabhas Asit Senapati Zydus School For Excellence, Ahmedabad Gujarat, India aabhas2211@gmail.com Nipun Batra Indian Institute of Technology (IIT), Gandhinagar Gujarat, India nipun.batra@iitgn.ac.in

ABSTRACT

Given the pandemic and the high air pollution in large parts of the world, masks have become ubiquitous. In this poster, we present our vision and work-in-progress (WIP) towards leveraging the ubiquity of masks for health sensing and persuasion. We envision masks to monitor health-related parameters such as i) temperature; ii) lung activity, among others. We also envision that retrofitting masks with sensors and display to show localized pollution can create awareness about air pollution. In this WIP, we present a smart mask, *Naqaab*¹, that measures forced vital capacity (FVC) of the lung using a retrofitted microphone. We evaluated the measured lung parameter on eight persons using an Incentive Spirometer² and found that our smart mask accurately measures incentive lung capacity. *Naqaab* also measures pollution exposure and indicates via different LED colours. We envision using such a system for eco feedback.

CCS CONCEPTS

• Human-centered computing → Interaction devices.

KEYWORDS

smart mask; air pollution; air pollution wearable

ACM Reference Format:

Rishiraj Adhikary, Tanmay Srivastava, Prerna Khanna, Aabhas Asit Senapati, and Nipun Batra. 2020. Naqaab: Towards health sensing and persuasion via masks. In Adjunct Proceedings of the 2020 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2020 ACM International Symposium on Wearable Computers (UbiComp/ISWC '20 Adjunct), September 12–16, 2020, Virtual Event, Mexico. ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3410530.3414403

²https://en.wikipedia.org/wiki/Incentive_spirometer

UbiComp/ISWC '20 Adjunct, September 12–16, 2020, Virtual Event, Mexico

© 2020 Copyright held by the owner/author(s).

ACM ISBN 978-1-4503-8076-8/20/09.

https://doi.org/10.1145/3410530.3414403

1 INTRODUCTION

Usage of face mask has become *ubiquitous*, especially after the spread of coronavirus 2 (SARS-CoV-2). The World Health Organisation (WHO)³ strongly advises health workers and caregivers of SARS-CoV-2 infected patients to wear a mask. The general public is encouraged to wear a mask in public places. The likely advantages of the use of masks by healthy people and the general public include:

- Reduced potential exposure risk from the infected person before they develop symptoms.
- Reduced potential stigmatization of individuals wearing masks to prevent infecting others.
- Making people feel they can play a role in contributing to stopping the spread of the virus.

The study by [5] has found discrepancies in the general public and community settings among different countries on the effectiveness of the mask. Although the effectiveness of face mask for preventing infections from SARS-CoV-2 is an active area of research, there is a consensus on the efficacy of mask to avoid air pollution-related diseases [2, 3]. Given the ubiquity of masks, in this work in progress, we explore masks as a sensing and persuasion wearable.

Air pollution is the cause and aggravating factor of many respiratory diseases like chronic obstructive pulmonary disease (COPD) [4, 10], asthma [9, 10], and lung cancer [12, 13]. Beside measuring lung parameters, a mask can also act as a persuasive device by reporting exposed pollution levels using an on-mask LED. Real-time air pollution information via the mask would empower people to make choices.

Previous work has proposed measuring lung function using smartphones [6]. Given the ubiquity of masks, we measured the incentive lung capacity (known as FVC or Forced Vital Capacity) using the microphone as a sensor embedded in the mask (Figure 1). We compared our result with a spirometer and found that the estimated incentive lung capacity (inhale cycle of FVC) to be 100% accurate with the incentive lung capacity reported by the Spirometer. We also measured air quality using a Carbon Monoxide (CO) sensor and report its efficacy by creating a source of CO in a closed room. We are currently working on i) measuring the amount of air an

¹Naqaab means mask in Hindi

Permission to make digital or hard copies of part or all of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s).

 $^{^{3}} https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public/when-and-how-to-use-masks$

UbiComp/ISWC '20 Adjunct, September 12-16, 2020, Virtual Event, Mexico

Adhikary, Srivastava et al.



Figure 1: (a) A person wearing *Naqaab*. The green colour of the RGB LED indicates the pollutant level around the user. (b) The interface of the mobile application showing pollutant level and lung parameters. (c) The green LED indicated that the pollutant levels are low. (d) In the presence of smoke (from incense stick in this case) rise in pollutant level is indicated by red LED.

individual can force out of her lungs in one second (known as FEC or Forced Expiratory Volume). FEC, in combination with FVC, gives a quantitative measure of the health of the lung and ii) measuring human temperature using an IR based thermometer.

2 APPROACH

We planned our prototype over a surgical mask, given that they are light and thin. A successful prototype over a surgical mask ensures that the prototype would work on any other commercial mask available.

We now talk about sensing lung parameter followed by signal processing, spirometry and measuring ambient air quality using a smart mask.

2.1 Lung Health Monitoring

Sensing Lung Parameter: After selecting an appropriate mask, we use the MEMS microphone embedded on the Arduino 33 BLE

sense microcontroller to record the breathing sound. The raw audio is sent to the user's smartphone over Bluetooth low energy (BLE) for processing. A LiPo battery was used to power the microcontroller. Note that during the experiment, we interfaced a memory card to the microcontroller to retrieve the raw audio. Figure 2 shows the setup.



Figure 2: The circuitry of Naqaab. (a) Shows the components of the system. (b) Shows the microphone on the Arduino Nano 33 BLE Sense.

Signal Processing: The participants were asked to take a deep breathe and exhale while keeping the smart mask intact on their face. The recorded audio was analysed. Previous study [1, 8] has shown that a person's breathing is divided into four different phases. They are inspiratory phase, inspiratory pause, expiratory phase and expiratory pause. The "pause" phases are of low frequency and saturated with background noise whereas the other phases are speech signals. We use Voice Activity Detection (VAD) [11] to segment noise and speech. We underline the steps for VAD below.



Figure 3: Flowchart of lung capacity estimation using microphone. (a) Mask with microphone and controller. (b) Raw input signal and (c) signal obtained after filtering. (d) estimating non silence time signal and associated energy. (e) combining user's empirical parameters to obtain FVC.

(1) The raw audio x(t) is filtered using a Butterworth high pass filter. To remove noise artefacts, we experimented with cut off frequencies ranging from 20 Hz to 50 Hz and found that Naqaab: Towards health sensing and persuasion via masks

at 40 Hz and order 5, the results were optimal. Let $t_{1,voice}$, $t_{1,silence}$ represent the inspiratory phase and pause respectively. Let $t_{2,voice}$, $t_{2,silence}$ represent the expiratory phase and pause respectively. The total time of the breathing cycle can be represented as

$$T_{breath-cycles}(i) = \sum_{i=1}^{n} t_{1voice_i} + t_{1silence_i} + t_{2voice_i} + t_{2silence_i}$$

where *i* represents i^{th} breathing cycle.

(2) The non-silent information is extracted from the raw signal using a window of 0.25 seconds. The window size was based on empirical evidence. The total time for non-silence can be given as :

$$T_{speech-phases-breath}(i) = \sum_{i=1}^{n} t_{1voice_i} + t_{2voice_i}$$

(3) The amplitude of the non-silence signal corresponds to the energy of the signal. Mathematically,

$$e = \sum |x(t)|^2 \tag{1}$$

(4) The energy *e* from Equation 1 is used to calculate the FVC which is given as,

$$FVC_m = \frac{15e}{100}(0.1524 * h - 0.0214 * a - 4.65)t$$
(2)

$$FVC_f = \frac{15e}{100}(0.1247 * h - 0.0216 * a - 3.59)t$$
(3)

where, a is the age of an individual in years, h is the height in inches, m for male and f for female. The average time duration of exhaling and inhaling is given by t. Equation 2 and 3 are based on empirical data and estimates as reported by [1].

The signal processing pipeline is shown in Figure 3. We use a spirometer to evaluate the measured Forced Vital Capacity of the lung.

2.2 Ambient Air Quality Monitoring:

We use a Carbon Monoxide sensor embedded on the mask to measure the air quality. We planned to measure particulate matter $(PM_{2,5})$ and display it using a 128x32 monochrome OLED. But restrictions put forward by the administration due to ongoing COVID-19 situation created hurdles of procurement. Hence, we used a traditional inorganic LED on the exterior of the mask to indicate the quality of air. We created a CO source by burning an incense stick to evaluate the efficacy of air quality monitoring.

The entire system is driven by the microcontroller powered by a 3.3V battery. The current consumption is < 169.6 mA with a 22 Ω load resistance across the CO sensor.

3 EVALUATION

Lung Function:

To evaluate our smart mask, we created a dataset of 16 audio samples and ground truth of spirometry data. We recruited eight individuals, five male and three female. None of the recruited individuals suffers from lung-related ailments. The study was conducted in UbiComp/ISWC '20 Adjunct, September 12-16, 2020, Virtual Event, Mexico



Figure 4: An individual using the three-ball spirometer.

Table 1: Participant statistics and result of evaluating *Naqaab* against the three-ball spirometer. The spirometer has output in one of the three ranges between $600 \text{ } cm^3/s$, 900 cm^3/s , and 1200 cm^3/s .

Subject	Age	Height	Gender	Time	Forced	Incentive	Spirometer
Number			Genuer		Vital	Lung	Reading
Nulliber					Capacity	Capacity	
	(years)	(inches)		(sec)	(L)	(cc/sec)	(cc/sec)
S1	19	70.8	М	5.5	4.60	1100.00	1200
				5.0	4.20	1128.20	1200
S2	17	69.6	М	3.0	2.50	889.60	900
				4.4	3.20	1150.00	1200
S3	49	69.6	М	2.2	1.65	733.33	900
				1.5	1.34	848.60	900
S4	16	60.6	F	3.5	2.90	1186.20	1200
				5.5	2.78	1183.60	1200
S5	51	69.0	М	5.7	4.81	1644.00	1200
				7.0	5.01	1775.40	1200
S6	45	66.0	F	4.5	3.00	985.20	1200
				4.7	2.60	1094.00	1200
S7	22	61.2	F	6.0	3.20	1166.60	1200
				5.0	3.23	1121.40	1200
S8	23	67.6	М	5.7	4.62	1666.60	1200
				5.5	4.80	1624.40	1200

a non-clinical lab setting. Our objective was to compare the FVC measure reported by our smart mask with a spirometer. We used a three-ball spirometer instead of a fine-grained one given the lockdown restrictions due to SARS-CoV-2. The three-ball spirometer measures incentive lung capacity (ILC) in three intervals, i.e $ILC \le 600 cm^3/s, 600 cm^3/s < ILC \le 900 cm^3/s \text{ and } ILC > 900 cm^3/s.$ One of our investigators demonstrated the use of the spirometer so that each participant is comfortable in using it. Each participant was asked to carry out two tasks. First, we asked each individual to wear our smart mask and exhale after taking a deep breath. Second, each individual repeated the first task using the spirometer without wearing the smart mask, as shown in Figure 4. The time difference between the first and the second task is not more than 15 minutes on an average. The experiment was conducted two times per subject to ensure correctness. Sharp deviation of the result from both the experiment indicates that a participant is not performing the task confidently and needs further supervision. The estimated ILC from the smart mask were classified into three levels, $ILC \le 600 cm^3/s, 600 cm^3/s < ILC \le 900 cm^3/s \text{ and } ILC > 900 cm^3/s$ given that our handheld spirometer reports ILC in the same three categories. The classification of the estimated ILC matched the classification reported by the spirometer for all the participants. The

recorded observations are shown in Table 1.

Ambient Air Quality Monitoring

To monitor the ambient air quality, we used a COTS-based MQ-7 Carbon Monoxide (CO) sensor instead of the planned particulate matter PM_{2.5} sensor due to procurement challenges gave the lockdown due to SARS-CoV-2. To evaluate its effectiveness, we monitored the CO value in a well-ventilated room for 30 minutes. We then exposed the ambient environment to burned incense sticks for the next 30 minutes as shown in Figure 1 (c) and Figure 1 (d) respectively. Incense sticks emit a mixture of fuel and oxidizer when burned, making them a source of CO. The difference in CO value was not more then 66.66%. We programmed the LED to change colours from green being clean air to red being hazardous. We envision such displays making people aware of the pollution in their surroundings, especially when air pollution locally can be significantly higher than the nearest ambient air quality monitor.

4 LIMITATIONS AND FUTURE WORK

Our project on the smart mask is a Work In Progress, and the lockdown announced by state administrations limited several aspects of it. The objective of our work is to engage with the *Ubicomp* community and take feedback. Below we mention the current limitations of our project and the future work.

- (1) Our smart mask currently measures the Forced Vital Capacity (FVC). Recent advances in the community successfully measure lung health using the Forced Expiratory Volume (FEV) in combination with FVC [6]. We are currently working on estimating the FEV parameter. Furthermore, our current system required the user to take deep breaths consciously. Such a system is thus not completely in-situ. In the future, we would like to develop techniques for in-situ measurement without active user involvement.
- (2) We monitored only carbon monoxide as an ambient air quality parameter. In the future, we will measure the particulate matter (PM_{2.5}) concentration. We will study the strategies for eco-feedback using OLED displays in the smart mask and carry out user studies to evaluate its efficacy.
- (3) We are also investigating the use of various energy harvesting techniques for powering the sensors and microcontroller.
- (4) On the design aspect, our objective is to create a retrofit that can easily be affixed on any mask. We assume that such a retrofit will leverage conductive thread and In-Situ Polymerization [7].

REFERENCES

- Ahmad Abushakra and Miad Faezipour. 2012. Lung capacity estimation through acoustic signal of breath. In 2012 IEEE 12th International Conference on Bioinformatics & Bioengineering (BIBE). IEEE, 386–391.
- [2] Anupama Balotra, Mukulika Maity, and Vinayak Naik. 2019. An Empirical Evaluation of the COTS Air Pollution Masks in a Highly Polluted Real Environment. In 2019 11th International Conference on Communication Systems & Networks (COMSNETS). IEEE, 842–848.
- [3] John W Cherrie, Andrew Apsley, Hilary Cowie, Susanne Steinle, William Mueller, Chun Lin, Claire J Horwell, Anne Sleeuwenhoek, and Miranda Loh. 2018. Effectiveness of face masks used to protect Beijing residents against particulate air pollution. Occupational and environmental medicine 75, 6 (2018), 446–452.
- [4] Annunziata Faustini, Massimo Stafoggia, Paola Colais, Giovanna Berti, Luigi Bisanti, Ennio Cadum, Achille Cernigliaro, Sandra Mallone, Corrado Scarnato,

and Francesco Forastiere. 2013. Air pollution and multiple acute respiratory outcomes. *European Respiratory Journal* 42, 2 (2013), 304–313.

- [5] Shuo Feng, Chen Shen, Nan Xia, Wei Song, Mengzhen Fan, and Benjamin J Cowling. 2020. Rational use of face masks in the COVID-19 pandemic. *The Lancet Respiratory Medicine* 8, 5 (2020), 434–436.
- [6] Mayank Goel, Elliot Saba, Maia Stiber, Eric Whitmire, Josh Fromm, Eric C Larson, Gaetano Borriello, and Shwetak N Patel. 2016. Spirocall: Measuring lung function over a phone call. In Proceedings of the 2016 CHI conference on human factors in computing systems. 5675–5685.
- [7] Cedric Honnet, Hannah Perner-Wilson, Marc Teyssier, Bruno Fruchard, Juergen Steimle, Ana C Baptista, and Paul Strohmeier. 2020. PolySense: Augmenting Textiles with Electrical Functionality using In-Situ Polymerization. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems. 1–13.
- [8] Peter Hult, Bengt Wranne, and Per Ask. 2000. A bioacoustic method for timing of the different phases of the breathing cycle and monitoring of breathing frequency. *Medical Engineering & Physics* 22, 6 (2000), 425–433.
- [9] Anna Karakatsani, Antonis Analitis, Dimitra Perifanou, Jon G Ayres, Roy M Harrison, Anastasia Kotronarou, Ilias G Kavouras, Juha Pekkanen, Kaarle Hämeri, Gerard PA Kos, et al. 2012. Particulate matter air pollution and respiratory symptoms in individuals having either asthma or chronic obstructive pulmonary disease: a European multicentre panel study. *Environmental Health* 11, 1 (2012), 75.
- [10] FJ Kelly and JC Fussell. 2011. Air pollution and airway disease. Clinical & Experimental Allergy 41, 8 (2011), 1059–1071.
- [11] Sen M Kuo, Bob H Lee, and Wenshun Tian. 2013. Real-time digital signal processing: fundamentals, implementations and applications. John Wiley & Sons.
- [12] Sonja N Sax, Ke Zu, and Julie E Goodman. 2013. Air pollution and lung cancer in Europe. *The Lancet Oncology* 14, 11 (2013), e439–e440.
- [13] Paolo Vineis, Gerard Hoek, Michal Krzyzanowski, Federica Vigna-Taglianti, Fabrizio Veglia, Luisa Airoldi, Herman Autrup, Alison Dunning, Seymour Garte, Pierre Hainaut, et al. 2006. Air pollution and risk of lung cancer in a prospective study in Europe. *International journal of cancer* 119, 1 (2006), 169–174.