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Towards Smart Face Masks by a Reusable, Wireless Sensor Patch and Tailored Data Analysis

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Summary:
The efficacy of FFP2 masks heavily depends on its fit and whether it is worn correctly. We present a reusable smart face mask sensor patch that detects mask fit by pressure modulation and alerts the user if it undershoots a certain threshold. The patch gets fixed on the outside of the mask fleece non-destructively, which opens the opportunity of adding other sensors, e.g. for hazardous gases. We test the patch with different subjects and discuss its sensitivity with respect to different external factors.

Keywords: wearable, smart face mask, health monitoring, data science

Background

Face masks have become ubiquitous during COVID-19 pandemic, underlining the importance of high-quality personal protective equipment. However, the efficacy of a face mask to protect the user against airborne viruses decreases if the mask is not worn correctly and/or does not match the user's physiognomy (mask fit or fit factor) or becomes too damp over time. Long-term users, e.g. healthworkers, are also advised to take breaks in wearing the mask to prevent fatigue.

Smart face masks can meet these challenges if they fulfill three tasks: i) monitoring environmental parameters that change within a respiratory cycle and are sensitive to mask fit, ii) processing this data on-board, and iii) alert the user in case of detected anomalies. An external device, e.g. a smartphone, may also carry out steps ii) and iii), in which case the mask should have a communication interface.

Description of the New Method or System

We design and construct a wireless sensor patch as shown in Fig. 1 that comes with a commercial sensor for pressure *p*, relative humidity *rH* and temperature *T* (BME280), a battery plug for power supply, a sound transducer and LEDs for alerting the user and a system-on-chip (SoC) that supports bluetooth low energy protocol (BLE). The patch is placed in a 3D-printed protective case with an opening at the position of the sensor. The diameter and height of the final case is 2,8 cm and 0,8 cm, respectively. We fix the patch on a FFP2 mask with a pair of magnetic rings, one within the case and the other on the far side of the mask fleece. Figure 1d) illustrates the case with the sensor patch being placed within the mask. We demonstrate, however, that the patch is also sensitive when placed at the outer layer of the mask, with the sensor facing the mask fleece.

In contrast to other approaches with reusable hardware components, the sensor patch can be used with commercially available masks [1-3] and is by design more robust and hygienic compared to devices placed within the mask [4-6]. The fixation on the outside of the filtering layers also opens the route for further hypothetical add-ons, e.g. sensors for CO_2 or other hazardous gases, to warn the user in an event of external threat.

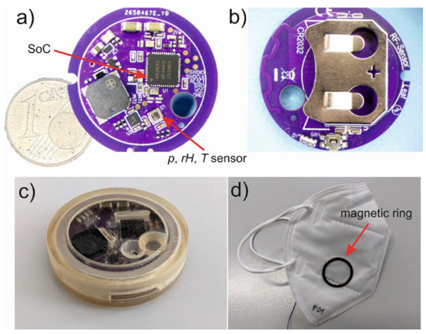

Fig. 1. Photograph of the a) top view and b) bottom view of the sensor patch. Red arrows mark the actual sensor and SoC, respectively. c) sensor patch in 3D-printed case with opening at sensor position. d) FFP2 mask with magnetic ring that fixates the patch from the outside. (Image Copyright: Fraunhofer IMM)

We test the device with respect to its capability to track the wear time and the fit quality of the mask for different users and under different conditions, like physical exercise, speech, etc.. We set up a suited algorithm that modifies and analyses the raw data under the constraints of being as time and power efficient as possible without losing sensitivity and selectivity.

Results and Discussion

While tracking mask wear time by signal modulation is straightforward, detecting the mask fit is rather challenging, as a defined leakage of about 2-3 mm reduces the efficacy of the mask significantly and must be detected by the sensors. User specific factors (tidal volume, physiognomy, physical activity, respiratory rate etc.) add further constraints. We test the sensitivity of the sensor patch when fixed on the outer layer of an FFP2 mask with different artificial leakages. We therefore punch holes of different diameter into the fleece and compare it to the best achievable fit with no intended leakage, i.e. zero leakage area. Figure 2 illustrates the effective pressure modulation Δp, where the ambient pressure, taken as a mean of intervals with a duration of Δt = 15 seconds, has been subtracted, for three leakage diameters, 0, 1 and 4 mm, respectively. The sampling rate is 20 Hz. In the example, the amplitude of the modulation decreases from about 50 Pa for the reference to about 30 and 25 Pa with increasing leakage area. Furthermore, the noise level of the measurement is between 5 and 10 Pa. A reliable statement on the fit quality therefore requires further data processing such as smoothing methods, treatment of outliers etc., as well as a (potentially) user-specific threshold value. We focus on the pressure signal since *rH* and *T* modulate less significantly once they reach equilibrium after a few minutes of wear time.

We record data sets from test subjects as they run through a predetermined performance profile on an ergometer. The acquisition time is 30 minutes. We split the datasets into intervals of 15 seconds, perform a smoothing and afterwards extract the signal stroke as well as the respiratory rate. Figure 3 shows the resulting correlation between both for a good (green circles) and bad (red diamonds) mask fit. Both datasets can be distinguished well by a threshold line (black dashed) that also accounts for the dependency of the signal stroke on the respiratory rate.

The proof of concept will be further discussed and tested with more and different subjects under different environmental conditions.

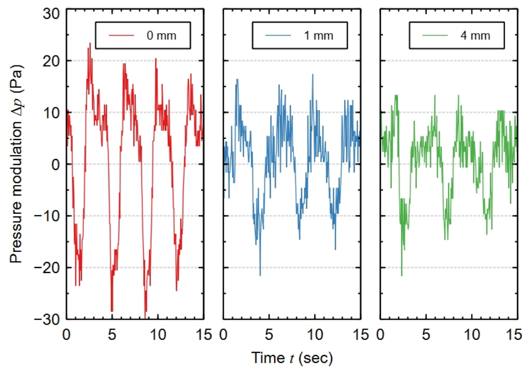

Fig. 2. Pressure signal minus the average (ambient) pressure for best achievable mask fit (0 mm) and two different artificial leakages (1 and 4mm) over a period of 15 seconds.

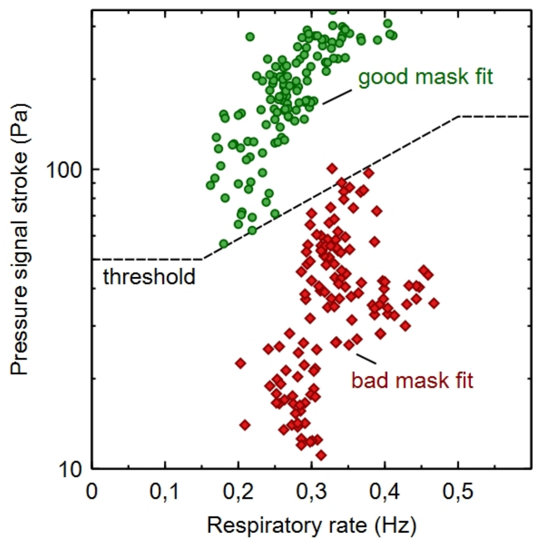

Fig. 3. Pressure signal stroke versus breathing frequency for a test subject having a good (green circles) and bad (red diamonds) mask fit. Each data point refers to a 15sec time interval of an overall acquisition time of 30 min. The dashed line marks a potential decision threshold.

References

[1] A. Fois, et al. , “Innovative Smart Face Mask to Protect Workers from COVID-19 Infection,” in 2021 IEEE MeMeA Symposium; doi: 10.1109/MeMeA52024.2021.9478739

[2] H. F. Fischer, et al., “Masquare: A Functional Smart Mask Design for Health Monitoring,” in 2021 Int. Symp. on Wearable Computers; doi: 10.1145/3460421.3478831

[3] J. Hyysalo, et al., *Internet of things* 18, 100511 (2022); doi: 10.1016/j.iot.2022.100511.

[4] Z. Ye, et. al., ACS nano 16, 5874 (2022); doi: 10.1021/acsnano.1c11041

[5] P. R. Priya, et al., IEEE Sensors J. 23, 13621 (2023); doi: 10.1109/JSEN.2023.3269388

[6] A. Curtiss, et al., Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 5, 1 (2021); doi: 10.1145/3494991