Masquare: a functional smart mask design for health monitoring

Hannah Friederike Fischer
DFKI GmbH
Germany, Berlin
Hannah.Fischer@dfki.de

Daniela Wittmann
DFKI GmbH
Germany, Berlin
Daniela.Wittmann@dfki.de

Alejandro Baucells Costa
DFKI GmbH
Germany, Berlin
Alejandro.Baucells_Costa@dfki.de

Bo Zhou
DFKI GmbH and TU Kaiserslautern
Germany, Kaiserslautern
Bo.Zhou@dfki.de

Gesche Joost
DFKI GmbH
Germany, Berlin
Gesche.Joost@dfki.de

Paul Lukowicz
DFKI GmbH and TU Kaiserslautern
Germany, Kaiserslautern
Paul.Lukowicz@dfki.de

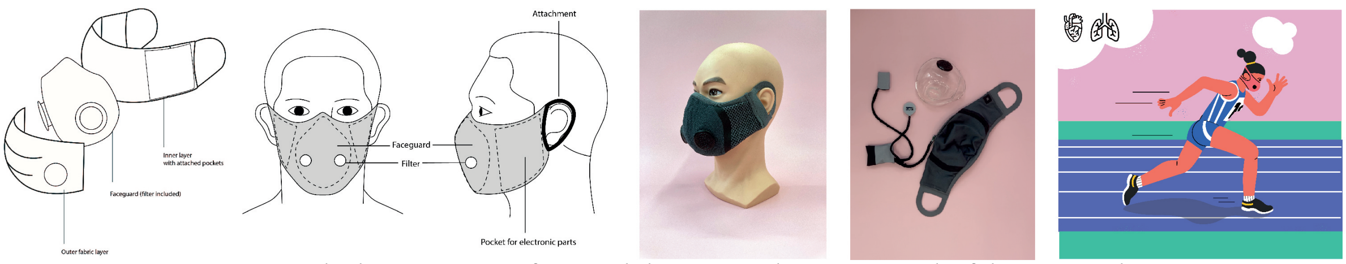

Figure 1: The design, prototype, functional electronics and use case example of the smart mask

ABSTRACT

We present a technology-garment co-designed smart mask concept, Masquare or Masque^2, to enable the daily face garments with cardio-respiratory health monitoring functions, through scientifically established results. Masquare can be used in various scenarios where both protection against harmful elements and continuous health status monitoring can benefit the user. Our design approach thoroughly considers the textile and garment integration to combine smart sensing technologies inside a face mask while keeping its traditional air filtering functions, all at the same time not deviating from the already generally accepted mask appearance.

CCS CONCEPTS

• **Computer systems organization → Embedded systems**.

KEYWORDS

Smart Mask, Human Computer Interaction, Health Monitoring, Human Centered Design, Participatory Design, Wearable Technology

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1 INTRODUCTION

As a face worn garment that serves health and aesthetic purposes, face masks have become widely accepted with the rise of the recent respiratory disease pandemic and have become an integral part of many people's daily life. In this design, we aim to equip face masks with additional functions to monitor the wearer's health status, using state-of-the art electronic technology and scientifically sound biomedical engineering knowledge. Our design concept is named Masquare, or Masque^2, hinting at the seamlessly added smart functions to the mask. The design incorporates sensing electronics with layered textile and 3D printed structures inside the face garment to find the equilibrium among sensing functions, wearer comfort, usability and social acceptance. We developed several use cases for such a functional smart mask.

2 RELATED WORK

2.1 Wearability of head- and face- mounted devices

The face is a very sensitive area to place garments or accessories. Especially when it comes to electronically placing wearable objects, little or no attention has been paid to the face as a placement option [1, 9]. However, because the face is central to the disclosure of health status, face-worn technologies are becoming increasingly relevant in the interest of application areas such as sports and medicine.

To ensure user acceptance of the smart mask, we applied the approaches of previous research to the face in a series of user workshops (see Fig. 3) and derived design recommendations in terms of component placement options, proxemics, attachment methods, and weight on the face. In contrast to wearables that are worn on the body and whose electronics can be integrated into the garment via a multi-layer textile structure [2]; the challenge with a mask is to keep the textile structure as thin as possible so as not to impair the signal quality of the sensors and not to hinder the user's

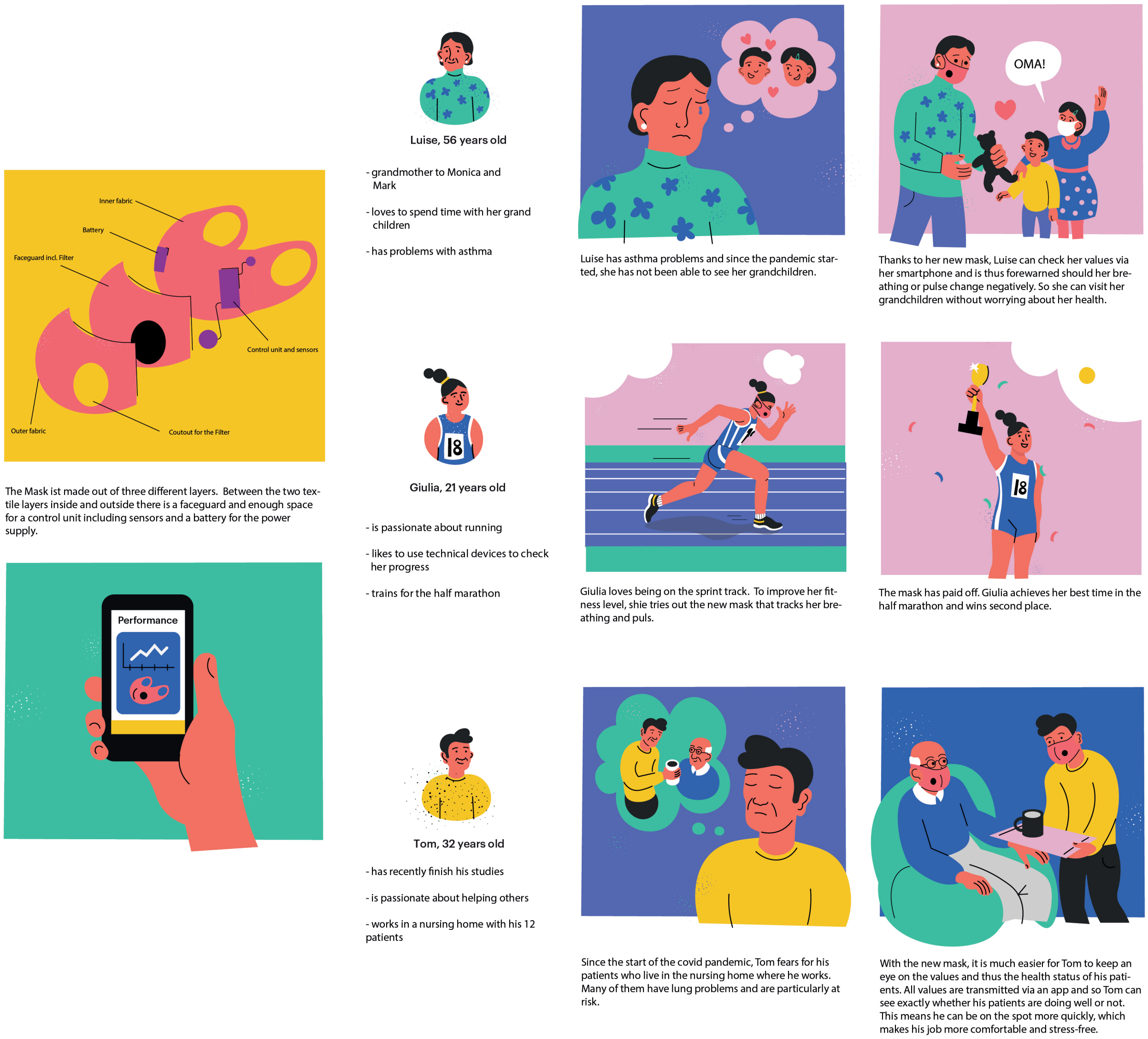

Figure 2: Use Case Descriptions

breathing freedom. We then designed the sensing components to evenly distribute across the mask as shown in Fig. 4 to have a thin profile and balanced weight distribution. A separate textile layer was dispensed for the integration of the electronics and the electronic components were integrated into the mask via pocket and click systems as shown in Fig. 5 and Fig. 6.

2.2 Technical Background

The cardio-respiratory functions include bio-signals from both our heart and lungs. The heartrate and oxygen saturation can be measured by photoplethysmogram (PPG) pulse-oximetry, which can be easily implemented with integrated sensors such as MAX30102 (Maxim). PPG sensors can be placed on various parts of the body's skin surface to pick up the heartrate and oxygen level information, including the side of the face [4, 6]. Measuring lung functions is medically termed pulmonary tests. Most wearable sensing methods can only achieve respiration rhythm level [5, 8] or rough intensity level monitoring. Differential embedded barometers were calibrated with a medical spirometer inside a mask design, achieving similar accuracy in deriving clinical pulmonary function test results such as the forced vital capacity (FVC) [10]. In [11], a barometer, a PPG sensor, and a motion sensor (IMU) were integrated in a technical demonstrator CoRSA, to monitor the entire cardio-respiratory functions, which is the technical foundation of our design.

Figure 3: User Workshop

3 USE CASES

Face masks are a traditional type of head garments: in Asia it has been widely used to fend of dust and pollens; athletes use air-restricting masks to simulate high-elevation training; some people wear patterned face masks for purely aesthetic reasons to express their identity or personality. The recent SARS-Cov-2 pandemic has also boosted the global usage and social acceptance of filtering masks. We developed several possible use cases for a smart mask that can both filter out harmful particles, but also monitor the wearers' cardio-respiratory status.

By incorporating smart health sensing, Masquare covers a wide range of potential use cases by both protecting against harmful particles and monitoring the cardio-respiratory status of the wearer. As described in Fig. 2, the smart mask is suitable for use in competitive sports to measure oxygen saturation and lung performance to help improve the athlete's performance. Another use case is the long-term use of a smart mask for rehabilitation or health monitoring. For example, long-term patients suffering from shortness of breath can have their lung capacity monitored continuously, regardless of time and place. Conventionally, in the case of a spirometer, patients have to directly breath through the same device, increasing the cross-infection risk. With Masquare, a personal health monitoring device can remove such risk of cross-infection from shared medical devices. In addition, it is conceivable that the smart mask could be used in occupational and medical contexts to alert users or caregivers to dangerous situations: Firefighters could be warned when they get into life-threatening situations, or asthma patients could be warned before an attack or would be able to analyze attack situations retrospectively.

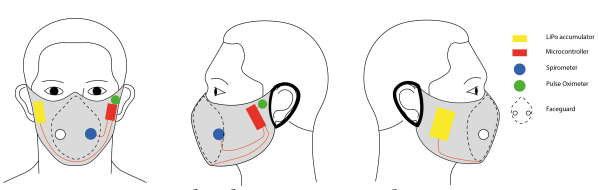

Figure 4: Technology component layout in Masquare

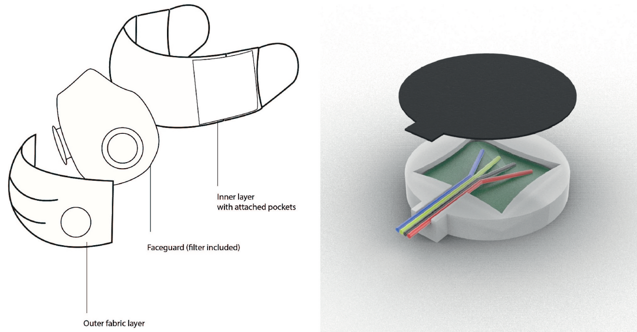

Figure 5: Textile Construction and 3D printed click mechanism for sensor integration

4 FUNCTIONAL DESIGN APPROACH

Masquare integrates smart sensing technologies while keeping the air particle filtering function. We describe our design approach from both the functional-driven and ergonomic design aspects.

4.1 Functional Design

Masquare monitors the cardio-respiratory functions by several integrated sensors. The central controller is based on an Arduino Nano 33 BLE Sense, which has BLE wireless connectivity and a rich selection of sensors in a compact footprint. The IMU sensor (LSM9DS1) provides the wearer's head motion data. We designed a custom PCB to expand the necessary digital interface and LiPo battery charging circuit. The associated access to the control is also located inside the mask and its well thought-out positioning allows uncomplicated access to the technical components. These can be completely removed from the mask, which makes the mask machine washable.

A pair of differential barometers: BME680 (dedicated module) inside and LPS22HB (integrated on the Arduino Nano Sense) outside, act as the spirometer, which measures the respiratory pressure or lung volume during inhalation and exhalation. According to [10], such a pair of differential baromters paired with a mask chamber can measure transient airflow as precise as a medical spirometer. The BME680 module is placed in the faceguard and held in place by a 3D printed click mechanism as shown in Fig. 5. An additional slot embedded at the level of the barometer on the inside of the mask prevents it from being covered by a material layer, which further increases the measurement accuracy.

The second sensor, a pulse oximeter (MAX30102), measures the heartrate and oxygen level by red and infrared light. Its position is on the side of the mask, at the level of the ear. Here, too, the sensor can be very easily inserted into the mask by means of a click-in system, and the exact position is precisely marked. The pulse oximeter is protected from the skin by a 0.3mm thin transparent cover of clear PVC material.

4.2 Ergonomic Design

Masquare consists of two flexible layers that gently hug the shape of the face. For protection and comfort, there is a silicone faceguard between the two layers, which also keeps the fabric at a distance from the face. It has an ergonomic shape, consists of flexible material

Figure 6: Image of current prototype of the smart mask

and it fits the face without leaving pressure marks on the skin. The faceguard can be removed through an opening on the underside of the mask and cleaned with gentle soap and water. The faceguard can also be sterilised with disinfectant when out and about.

Protection against potentially harmful air particles is provided by a filter embedded in the faceguard, which can be replaced with a simple twitch by hand. To do this, the cover is removed by gently turning it. The inserted filter material is replaced and the cover is put back on.

Masquare is equipped with two elastic straps that are placed behind the ears when the mask is put on. The battery supplies the electronic components with the necessary energy and is designed in such a way that it can be easily removed from the attached device and charged. It can be easily charged with a USB cable through the main control module. Spacer fabrics of various thickness are used to even out the layer that contains the electronics.

5 DISCUSSION AND OUTLOOK

With Masquare, we present a smart mask concept which integrates wireless smart sensing technologies seamlessly. Traditional face masks already serve the health protection purpose. Adding health status sensing function will further promote health awareness. In this specific design, we have integrated a virtual spirometer by a pair of differential barometers, a pulse-oximeter, and a physical motion activity sensor.

In the future we would like to add more functions to the Masquare smart sensing platform. First of all, the existing hardware has more sensing capabilities such as light, hand gesture, humidity and temperature. These sensors are already integrated inside the Masquare with the Arduino Nano Sense, and can be enabled by future software updates.

We also plan to elaborate the cardio-respiratory function by adding CO2 sensing, which may lead to a wearable metabolic analyzer for calorie tracking [7]. In a study Glabella [3], several PPG sensors were placed on different sites of the face to track the blood pressure by the temporal pulse differences. Masquare already has one such PPG sensor and our platform has the capability to drive more PPG sensors. Thus it is possible to duplicate the Glabella results and add blood pressure tracking function to the health monitoring.

For the ergonomics and usability aspect, additional support can be provided by an attached band that goes around the back of the head. This can be closed without looking by means of self-finding magnets and adjusted to the size of the back of the head. Some components such as the battery can also be moved to the band to have more balanced weight distribution.

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