# All-fabric triboelectric nanogenerator (AF-TENG) smart face mask: remote long-rate breathing monitoring and apnea alarm

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**Abstract**

Since the beginning of the COVID-19 pandemic, the use of face masks have become not only mandatory in several countries but also an acceptable approach for combating the pandemic. In the quest of design of effective and useful face mask, triboelectric nanogenerators (TENG) have been recently proposed. Novel functionalities are provided with the use of TENGS in face masks due to the induced a triboelectrification generated by the exhaled and inhaled breath, allowing its use as energy sensor. Nonetheless, within the facemask the presence of non-textile plastics or other common triboelectric (TE) materials can be undesired. Herein we propose the use of an all-fabric

TENG (AF-TENG) with the use of high molecular weight polyethylene (UHMWPE) and cotton fabric as negative and positive triboelectric layers. With these materials is possible to detect the breathing of the patient, which in the case of not detecting signal over a few minutes can trigger an alarm locally, providing valuable time. Also, in this article we have sent breathing signals locally and remotely to distances up to 20 km via Wi-Fi and LoRa the same as warning signals in case of detecting anomalies. This work reveals the use of TENGS in smart facemasks as an important tool to be used in difficult epidemiological periods to general public, bringing much more comfort and relax to patients and elderly in today's society, and based on pristine eco-friendly materials.

The pandemic outbreak produced by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in 2019,  has caused more than 6 million deaths around the world[1]. To prevent the widespread of COVID-19, the use of personal protective equipment (PPE) has become necessary. An example of PPE is the face mask which has become a daily-must for many persons around the world. Wearing a surgical face mask has been proved to be one of the most efficient methods to prevent virus propagation, as they can inhibit the transference of infecting agents, bacteria and viruses. Also, with the worldwide population growth, the use of face mask can be used as protection against pollution. Presently, the most used face masks and respirators are, respectively, surgical masks and N95 level respirators, which are fabricated from synthetic,  natural polymers or composites, typically polypropylene (PP), polyethylene (PE) among others. From these materials, melt-blown non-woven, especially nonwoven PP fabric, are the most commonly used[2]. In the era of the Internet-Of-Things it is not a surprise that researchers have decided to use the masks as smart devices, taking advantage of the high number of novel materials which have emerged: the integrated, flexible and fast electronics nowadays in the market, and the fast communication systems. Currently, face mask are focused on monitoring respiratory symptoms such as cough [3–5], apnea [6]or monitoring human respiration [7]

One of the advantages of using face masks is that exhaled breath can be used as a self-energy monitoring. In this sense, triboelectric nanogenerators (TENGs) are evolving very fast and their working principle is based on the conversion of mechanical energy into electricity by friction of their opposite electrocharged layers and could be used to remotely send health state constants [8]. In the case of facemasks, they make use of the momentum change produced by either the air inhalation or air exhalation during the breathing, converting small mechanical motion into an electrical signal.

TENGs have been recently employed for human-health care [9,10], biomedical sensing [11,12] , gas sensing [13], moisture detection and studying the possibilities of breath monitoring [7], movements and gestures [14,15], often integrated with clothing in what is called wearable TENGs (WTENGs). In fact, triboelectric air filters (TAF) have been employed for filtering [10,16] from dust [17–19] or viruses [20,21], where materials and design play a fundamental role [22]. The idea of breathing monitoring or moisture sensing[23], particularly using TENGs has recently gained attention [6,8,24], mostly by incorporating a TENG to the facemask, which was activated by the breathing force. However, most of TENGS are based on classic triboelectric materials such as polytetrafluoroethylene (PTFE) or polyvinylidene fluoride (PVDF)and are not fully integrated into the face mask. Similarly, some key fundamentals of face masks, such as breathability and wearing comfort are often neglected [7,25]One ideal approach could be using similar materials for the breath facemask fabrics, being fully integrable and optimal from a materials perspective. Conversely, Gathak et al. [26] proposed the use of different materials such as nylon, PP or Polyurethane (PU) for the triboelectric layers of a facemask, which can be used as a starting point for re-discovering health friendly materials for TENG face masks, which however were not tested for breathing monitoring. By measuring breathing rhythm of a person we could detect respiratory diseases such as cough or apnea among others [4], providing fundamental information of the patient's health state.

Smart face mask research is mainly focused on remote monitoring, i.e. monitoring breathing near the face mask and the person wearing it. This is clearly useful in an hospital or household scenario, and is mainly due to the limitations related to design and electronics of face mask, which are connected directly [8]. The use of technologies such as Lo-Ra (long range) could enhance this signal towards long distance range and although information is minimized, it can provide an alternative solution to wireless systems, especially for TENGs, whose alarms have always been based on WIFI[27] or Bluetooth[24,28] and highly dependent on IoT systems. This system can be controlled and accessed remotely through an access network through the internet[29].

In this work, we present the design a smart facemask for respiratory monitoring based on all fabrics (AF-TENG). The smart facemask application is presented into two different systems: on one hand a local alarm system is integrated into the mask and as the absence of breathing is detected (apnea detector), a signal is sent to an LCD (Liquid Cristal Display) screen and a light and noise alarm is activated. On the other hand, breathing monitoring can be performed locally and remotely. Remotely, by sending the breathing signal to IoT platforms which, when using LoRa, far distances in interurban areas can be reached (up to 20 kms) and locally by connecting the TENGS to an ADC (analogue digital converter), to a display which will show the corresponding warning message programmed.

In this work, the eco-friendly all-fabric TENG is based on the use of both cotton and UHMWPE (ultra-high molecular weight polyethylene)-based systems, fabricated with economically viable methods and feasible long-scale fabrication. UHMWPE is a potential material for its biocompatibility and biosafety, with a high resistance and strength [30], barely employed as triboelectric material despite is high negative charge affinity [31] which can be obtained its fabrics are used in clothing [32]. This AF-TENG has been included into a prototype facemask and it is capable of detecting the presence of breathing, fully autonomous, which can detect an instant safety hazard such as the absence of breathing (apnea) sending a warning message using a system based on an Arduino microcontroller. Furthermore, this AF-TENG face-mask system is capable of monitoring in real time the presence of breathing and send this information thanks to the IoT network and telecommunications remotely and wireless. The fabricated AF-TENG aims for the creation of safe and eco-friendly all-fabric based smart face mask systems, which thanks to the IoT is capable of monitoring respiratory diseases.

## Experimental section

### Preparation of triboelectric nanomaterials

UHWMPE, with tradename Dyneema (Ultra high molecular weight polyethylene) was purchased from Extremetextil (Denmark) and StickersLab (Italy). Cotton fabrics were provided by Beijing Institute of Fashion Technology, China. The different composition of the samples is shown in Table 1. Cotton fabrics were treated in an ozone cleaner during 30 s (Jelight UVO Cleaner Model 18). All textiles were cleaned with the use of a nitrogen gun. In all cases cotton fabric has been used as positive layer and UHWMPE as negative triboelectric layer, while other composites have been employed also for the negative layer (see Supplementary Information).

Table 1: Triboelectric nanomaterials employed in this work for the negative layer.

| Name | Sample | Composition | Fabric construction | Density (g/qm) | Negative triboelectric layer |
|---|---|---|---|---|---|
| UHWMPE | UHWMPE | UHWMPE | 2D Plain wave pattern | 430 | StikersLab |
| Composite 1 | Dyneema composite fabric + woven | Dyneema, Polyester (PES), Dyneema, 50den Polyester | Folie, laminate, taffeta | 102 | Extremetextil |
| Composite 2 | Dyneema, Polyester (PES), Bio-based Dyneema | Dyneema, Polyester (PES), Bio-based Dyneema | Folie, laminate | 18 | Extremetextil |
| Composite 3 | Dyneema-Denim, 62% Dyneema, 38% Cotton | cotton, Dyneema, 62% Dyneema, 38% Cotton | Twill | 430 | Extremetextil |

First, fabric samples were precisely cut into different sizes (20x20)mm$^2$ , (40x40)mm$^2$ and (60x60)mm$^2$. Electrical wires (RS-Amidata S.A.U) were sandwiched between the fabric electrode and conductive copper tape. For testing outside the facemask, an arc-shape TENG formed by sticking the two electrode films onto either Polyethylene terephthalate (PET) or Kapton film (Resinas Castro S.L) were employed, where the distance between the triboelectric electrodes could be adjusted by designed dimension of Kapton film.

**Characterization of the Triboelectric fabrics**

Fourier transform infrared spectrometer (FTIR) was performed on Thermofisher Nicolet 5700 spectrometer in ATR mode. Scanning electron microscopy (SEM) imaging was carried out in a Apreo 2S (ThermoFisher) in low vacuum mode working at 0.5 mbar. Contact angle was measured with a goniometer (Ramé-Hart 200 F1).

**Characterization of the triboelectric performance**

All TENGs evaluated worked on contact mode. To evaluate the electrical performance of the all-fabric (AF-TENG), an oscilloscope (Tektronix, DPO 2012B) was employed. Before the measurement, the two triboelectric layers were separated by a certain distance, being this distance constant for all samples. Probes used for measuring have both 1x or 10x amplifiers. A homemade setup was employed, based on a piston Stirling engine connected to an AC motor and a frequency controller. This setup allows variable frequency range between 2 to 10 Hz. While the mechanical stimulus was supplied by this setup, the open-circuit voltage was measured using an oscilloscope and, similarly, the short-circuit current was also measured using the oscilloscope coupled to an Low noise current preamplifier SR570 (Standford Research Systems)[33].

**Signal transmission**

Remotely transmission of the TENG pulses by using LoRa (Long Range) wireless IoT communication protocol by using an MKR WAN 1300 board of Arduino two out of the six analogue channels to receive the TENG electrical pulses and send the information via TENG pulses via LoRA. In addition, the receptor can be positioned up to 20 kms far away from the emitter in interurban areas and it is made of a gateway that consists of a concentrator module RAK2245and a Raspberry Pi 4. This gateway is connected to Wi-Fi and registered to The things of Stack (TTS).

## Results and Discussion

### Fabrics characterization

In this work, AF-TENG was fabricated using cotton fabric (CF) as positive triboelectric layer and UHMWPE (ultra-high molecular weight polyethylene) as negative triboelectric layer. More samples with different UHWMPE fabrics can be observed in Figure S1, in which other UHWMPE-based composites have been studied. SEM was employed to study the morphology of the different fabrics, as presented in Figure 1 (a). It is clear that both samples present a different braiding of the samples, being UHMWPE a plain knitted fabric whereas cotton fabric shows the fabric much more densely packed. For the remaining samples, Figure S2 shows SEM images, in which the also braiding scan be observed for each of the samples.

The FTIR spectra of UHMWPE is shown in Figure 1 (b). Primary, four fundamental bands for UHMWPE could be found including two strong CH stretching modes at 2846 and 2912 $cm^{-1}$, a band at 1462-1472 $cm^{-1}$, corresponding to the bending of $-CH_2-$ and the $CH_2$ rocking mode at 719-727 $cm^{-1}$, and are consistent with those for HDPE or UHMWPE polymers [34]. The typical functional groups of cotton fabrics appear around 3328 $cm^{-1}$, 3273 $cm^{-1}$, 2893 $cm^{-1}$, 1066 $cm^{-1}$ and 1626 $cm^{-1}$ are assigned to the stretching vibration of C–OH, C–H, C–O–C and bending vibration of C–H, respectively[35]. Figure S3 presents the FTIR spectra of the other samples studied, in which modes attributed to the other compounds such as polyester (PES) which is one of the components, are also observed.

One important parameter in facemasks materials is hydrophobicity, as the virus bacteria normally lives within a water medium. Higher hydrophobicity, i.e higher contact angle, is a desired property for the face mask, and one of the approaches for new smart face masks [2] As shown in Figure 1 (c), the contact angle of UHWMPE is 115º while 137º for cotton fabric, mostly due to a pre-treatment with ozone. In both cases the drop after 5 minutes is still non fully absorbed, but the decrease on the contact angle points out that the fabrics do in fact let the water be absorbed, which is beneficial for breathing purposes, out the scope of this work. This behavior is similar for all the samples shown Figure S4 except for the first sample, which is almost immediately adsorbed due to the plain wave knitted which has a big pore size. It is important to mention that both fabrics present a good water vapor breathability as show by Figure S1(b).

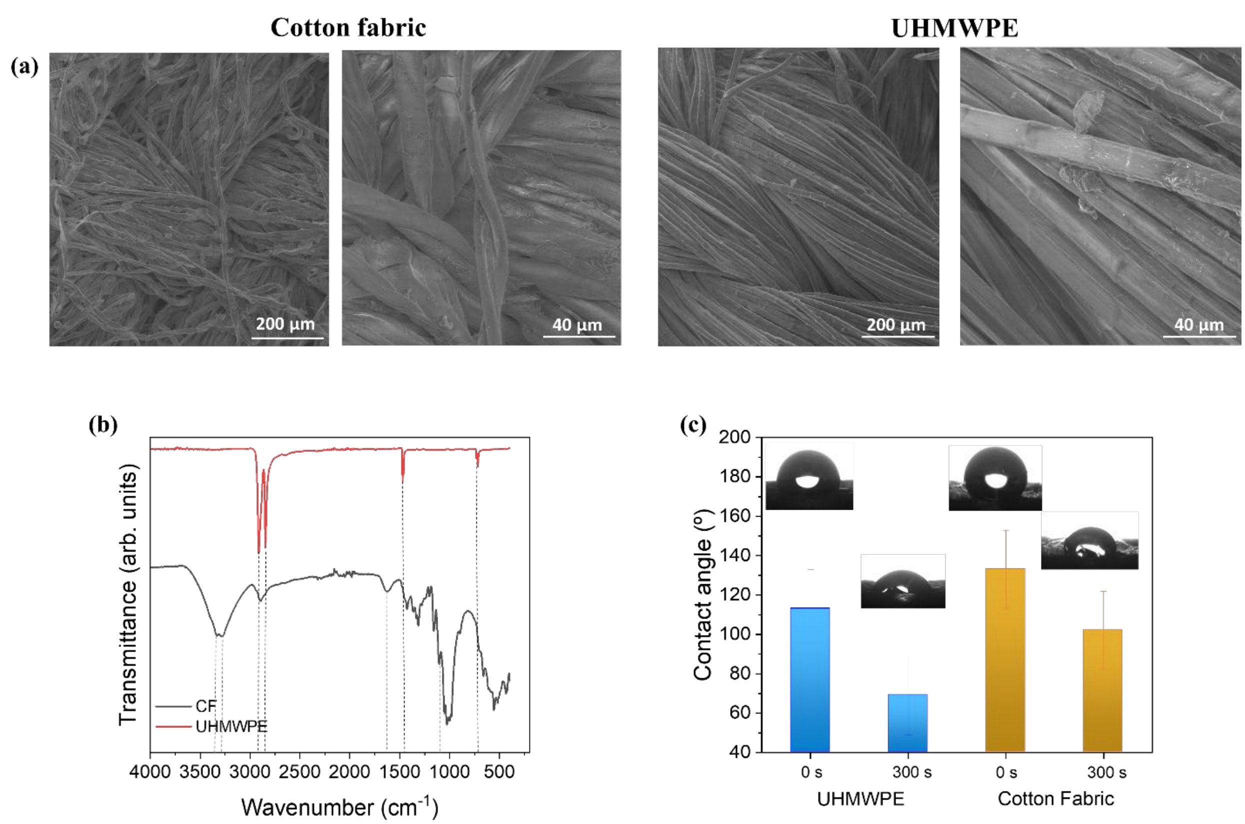

Figure 1: (a) SEM micrographs (b) FTIR spectra of the studied triboelectric layers and (c) contact angle measurements.

**Triboelectric performance**

To test the response of the of the All fabric-TENG, a homemade setup was employed with a piston to control the movement of the TENG and determine the voltage output. The working principle of the AF-TENG has been summarized in Fig. S5. A simple device was designed with aid of PET film for initial testing, as shown in Figure 2 (a) The distance of the arch-shaped AF-TENG can be controlled by adjusting the PET/kapton fabric size but was maintained constant for all measurements.

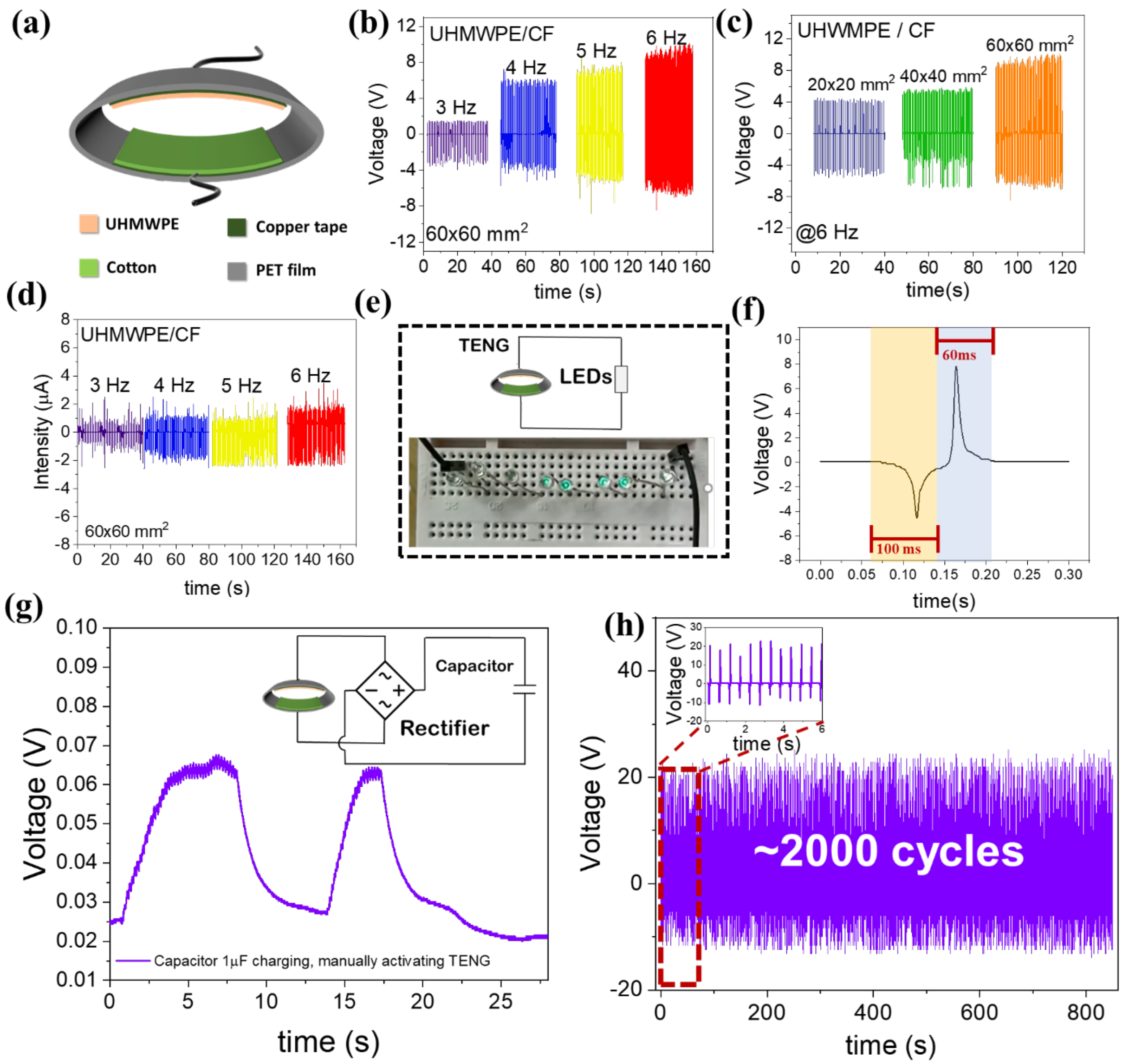


Figure 2: (a) Representation of the arc-shaped TENG device employed for characterization. The electrical output characterization of the AF-TENG (b) Dependence of the voltage output with the frequency (c) Dependence of the voltage output with the TENG size (d) Dependence of the intensity with the frequency (e) Output electrical power used to switch on 8 green LEDs with the AF-TENG and the corresponding circuit (f) Pulse shape with its positive and negative component. Probes were set to x10. (g) the response of a 1 μF capacitor triggered by tapping manually and (h) Stability and durability test over 2000 cycles.

Firstly, the effect of the amplitude of the frequency was analysed by employing different frequencies of 3, 4, 5 and 6 Hz, respectively. As observed in Figure 2 (b), by increasing the frequency we obtained higher response on voltage, as clearly observed for 6Hz which reaches ~10V. This effect is commonly attributed to the collection of surface charges on the surface of the triboelectric layers which could not be neutralized at high frequencies [29]

Moreover, the effect of the size was also investigated by using different size TENGs of 20x20, 40x40 or 60x60 $mm^2$ shown in Figure 2 (c). In this case, higher responses are observed for higher areas, as higher triboelectric contact is translated into higher surface charge density exchange. For the remaining samples studied, voltage output dependence on either frequency or TENG size can be observed in Fig. S6. The current was also studied for the same AF-TENGs, in which the highest current measured was within the micro ampere range Figure 2 (d). It is important to note that the back-contact for electrons collection is made of Cu tape, which covers the back side of each triboelectric layer. It was also tested the use of smaller Cu tape area which is shown in Fig. S7. Reducing the area of the electron-collector decreases the voltage output, still being in an range to be used in this application.

The AF-TENG, with an area of 60x60$mm^2$ was connected to multiple light-emitting diodes (LEDs). At a frequency of 2.5 Hz, the AF-TENG, was able to illuminate 8 LEDs connected in series (Figure 2 (e)). Note that in our case we are not using any bridge rectifier because negative component of the pulse is eliminated by the diode.

Regarding the voltage pulse shape, as observed in Figure 2 (f), the negative and positive components of the pulse can be observed in the 60x60$mm^2$ AF-TENG. Here, the pulse amplitude is slightly higher in the positive voltage region than in the negative. The reason for this asymmetry could be explained because the motor compression speed is slightly higher than the traction for which piston has to go against the gravity and lift its own weight. Furthermore, higher frequency and as a results, higher speed, is related to narrower and higher pulse amplitudes .A study of TENG deformation speed vs. amplitude of the peaks can be read in [36]

Also, an application of the feasible self-powered TENG, a 1 μF capacitor was finger-tapping charged , with the aid of a bridge rectifier in this case Figure 2 (g), shows that the AF-TENG can charge a 1 μF capacitor to ~0.06 V in less than 10 s, which can be observed in Video S1, showing also the potential AF-TENG has for self-powering and charging.

Moreover, to evaluate the stability and durability of the designed device, tests of AF-TENG durability were performed under along-time operation, working at 4 Hz of during 1000 seconds. The measured voltage, shown in Figure 2 (g), demonstrates that the output voltage is constant within ~20V, proving that the system is stable and robust over long working periods. Moreover, considering than a healthy adult respiration rate is 14 breaths per minute [41] and with this test we have full TENG contact each second, this testing could be compared to more than two hours of use.

**Performance under breathing**

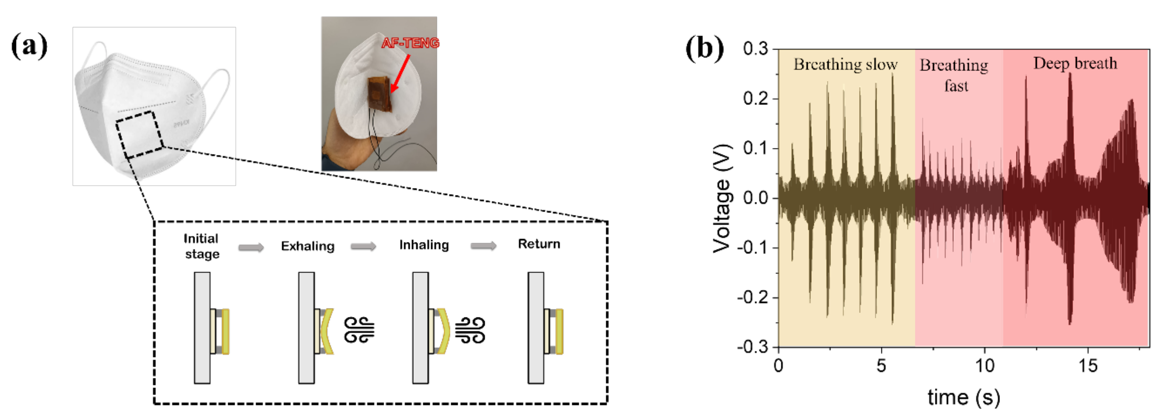


Figure 3: (a) Working principle and placing of the AF-TENG, powered by human breathing and (b) the output comparison of the AF-TENG depending on the breathing speed and strength.

Herein we applied our AF-TENG mask for human breathing monitoring as shown in Figure 3 and Movie S2 and S3. Figure 3 (a) shows the placing of the AF-TENG within the facemask. For this test we have employed the 40x40 $mm^2$ AF-TENG, which has a good sensitivity for breathing rhythm detection. Figure 3 (b) shows the possibility of discerning among different breathing rates and patterns, which is fundamental for detecting asthma, apnea or any other respiratory disease [8,37]. This smart mask system shows high evidence of the correlation between the voltage generated and the breathing rate. As shown in Figure 3 (b) we were able to distinguish between a fast breathing and a slow breathing. For fast breathing, the higher frequency and lower intensity of the pulses were measured because breathing force exerted on the mask decreases when the breathing is shorter. Also, deep breathing could be identified, in which the shape of the pulse becomes wider, due to the longer time the TENGs are in contact. This result shows that there is a high difference in the application of TENGs for breathing systems alarms as compared with others. Moreover, as during breathing moisture could affect measurements, behaviour under humidity was tested by placing the AF-TENG in a climatic chamber and measure its performance soon after, as shown in Fig S8. With increasing humidity, the performance of the AF-TENG is affected, with 90% it drops to 10V, which is still a good value for the applicability of the AF-TENG.

Commonly used as Fire Alarms, TENGs-based alarm are triggered on the presence of a voltage output[29,38]. In the case of a breathing alarm, to detect apnea for instance, the dependence is over time i.e we need to add a condition dependent on time, which is shown on the following section.

**Local and remote alarm system**

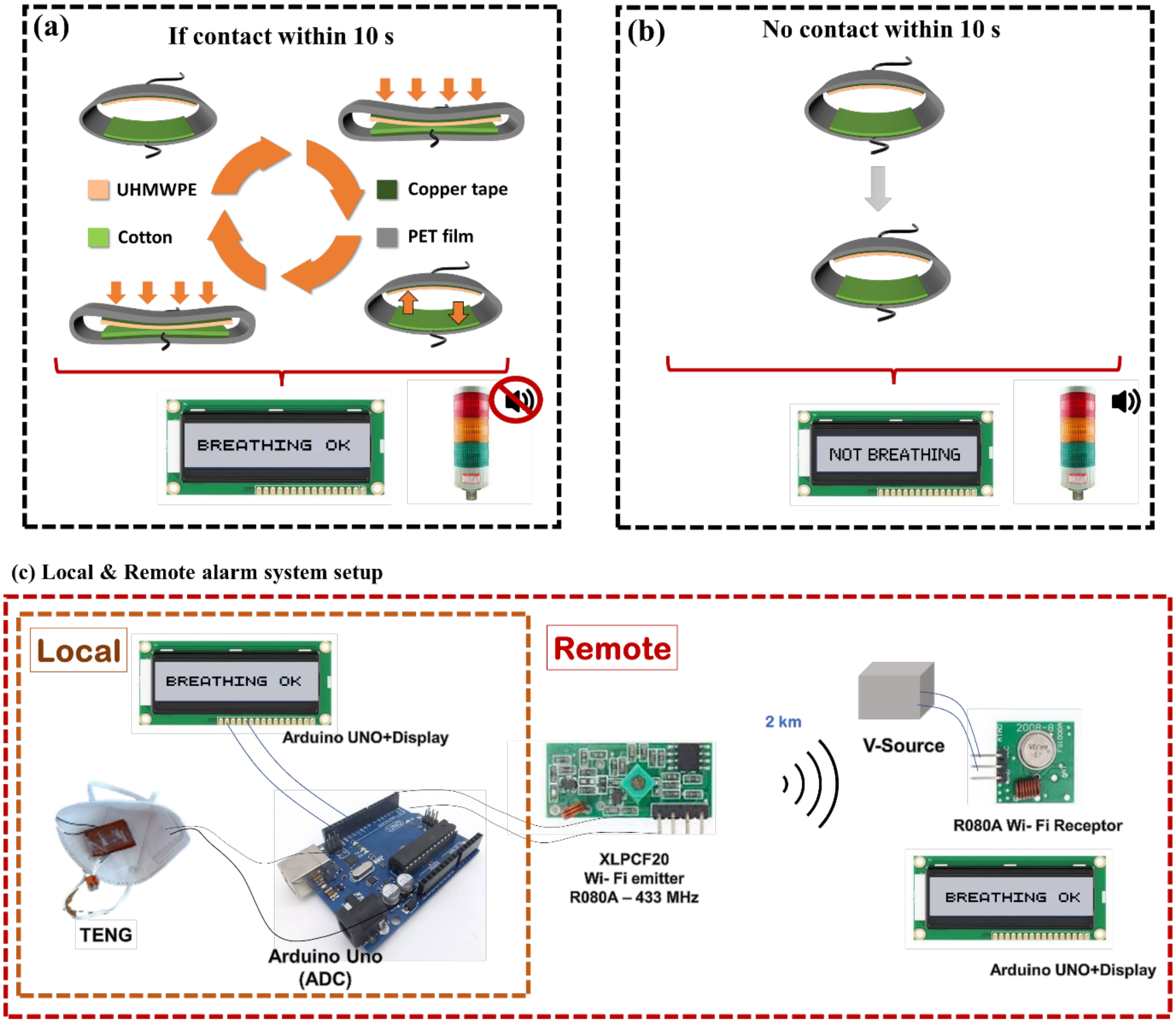


Figure 4: Working principle of the circuit alarm for detecting breathing (a) if breathing, the AF-TENG is activated and (b) if it is not activated within 10 s the alarm goes on and (c) Local and Remote alarm system setups.

To demonstrate the feasibility in a real scenario, the AF-TENG mask was connected to an alarm system, developed to determine the lack of breathing. The experimental set-up is very similar to the one described elsewhere [39,40]. Two kinds of systems were proposed for warning and breathing monitoring (see Figure 4), all electronic components used are described in Fig. S9. First, one local and second, other one remote. In the first one, the electrodes of the TENG attached to the face mask were connected to an Arduino Uno. A threshold was programmed to determine the absence of breathing and therefore the the alarm started a beeping sound, or a warning message was shown in a display (Figure 4 (a)-(b)).. When voltage generated by the TENG overpassed the threshold repeatedly, the display showed the message “BREATHING OK”. When the voltage amplitude of the TENG was not higher than the threshold during a period of time (t =10 seconds in our case), the display of the alarm system changed from “BREATHING OK” to “NOT BREATHING” and the noise alarm started to beep (See video S2 and video S3). This intensity is indirectly linked with the breathing force, which for each patient might be different depending on factors such age or breathing conditions[41,42], and thus a variable can be created with the maximum amplitude and if the decrease over that time span is higher than a certain percentage, we can conclude some breathing anomaly. This configuration is similar to the ones present nowadays in hospitals with patients whose vital constants are being monitored continuously by sensors fixed to their body. The second one is used for warning remotely with an alarm or with a message in a display the problem a patient can have when breathing anomaly. For this, a Wi-Fi emitter XLPCF20 connected to an ADC (Analogue to Digital Converter) designed with an Arduino UNO and programmed in such a way that as soon as the voltage generated by the TENG surpassed a voltage threshold, a digital output would pass from 0V to 5V in order to activate the Wi-Fi emitter. Then, a Wi-Fi receptor would receive the corresponding signal from the emitter and would supply 5 V to another Arduino programmed for sending the message of “BREATHING OK” or “NOT BREATHING” to a display using the Liquid Crystal library. The display can be placed up to a distance of 2 km from the emitter. This application will help many patients in hospitals or elderly in their own houses to walk and do normal life while at the same time their breathing is remotely controlled and monitored.

**Remote breathing monitoring based on IoT and Lo-Ra**

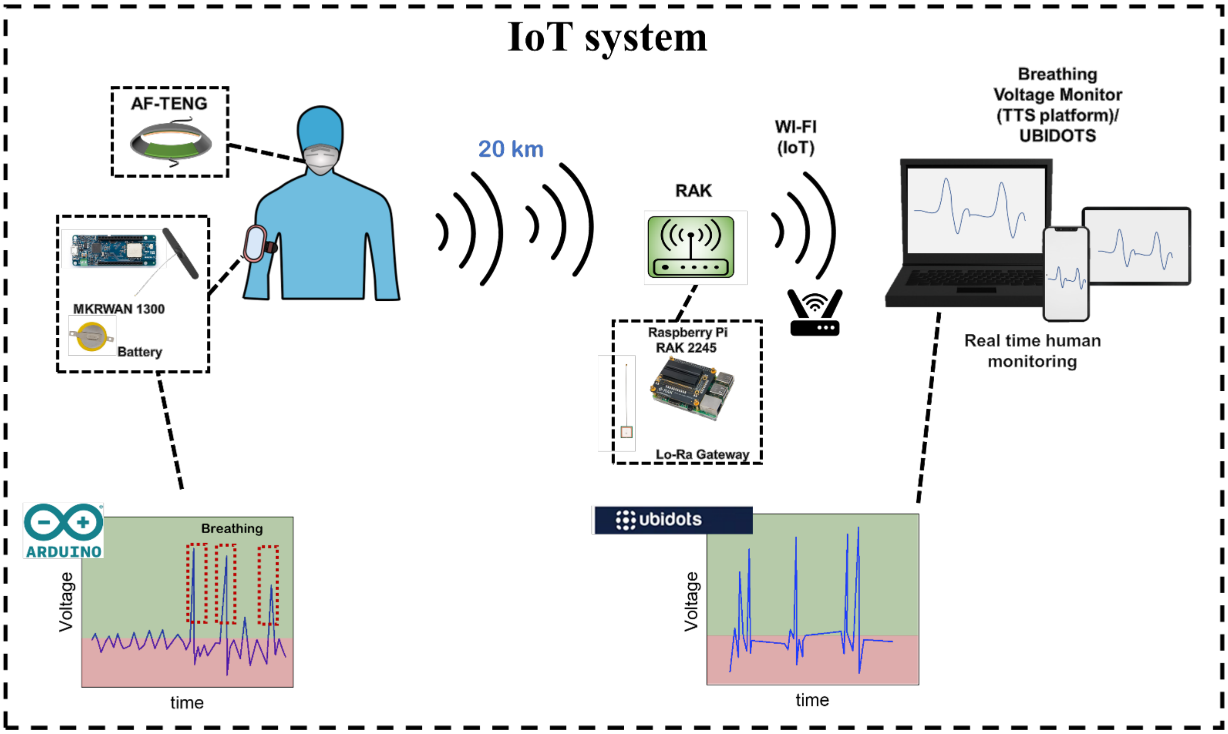


Figure 5: Electronic and communications set-up of the breathing monitoring remotely using the LoRa protocole.

Inside the second application of remotely monitoring, breathing rhythm detected by the AF-TENG was successfully monitored and saved by using an IoT-based system (see Figure 5 and video S4). This system consists of the AF-TENG, with its electrodes connected to a LoRA emitter (MKRWAN1300) and sends voltage pulses generated by the TENG to a LoRA receptor (RAK2400) operating as a gateway. This RAK was connected by Wi-Fi to the internet, and this allowed monitoring the voltage produced by the TENG when its layers were either compressed or relaxed depending on the type of the user breath (inhalation/exhalation). A similar set-up is described in [43] where a warning message was sent to the IoT platform used (the Things of Stack) instead of a continuous voltage signal as it is in this work, therefore not showing a simple warning message but sending complete information of the patient breathing. As reported in the video S4, MKRWAN1300 can be placed into a bracelet with a small battery working as a power supply. In order to plot the voltage produced when breathing, UBIDOTS platform [44] connected to TTS was used and as a result, breathing rhythm was monitored due to the inhalation/ exhalation motion produced in the mask.

To summarize, in this work we propose a novel technology for smart face mask, bringing the possibility of both remote and local breathing monitoring. In this context, substantial efforts have been discovered on research on the last years, which are mostly summarized on Table 2 . It should be mentioned that the topic of face masks has been widely covered on the last years [45], being TENGs-assisted face mask a small subsection, with high potential mainly for two reasons: the electrostatic filtration and the possibility of monitoring [45]. An early report by Liu et al. [46] depicted an adsorption face mask based on electrospun nanofiber film (PVDF-ESNF) and a triboelectric nanogenerator (TENG) driven by respiration (R-TENG). A similar system with other materials such PP/PTFE face mask [47], polyimide (PI) [48] or polyvinyl alcohol (PVA) [49] also proposed. The use of other fabrics such as nylon with PTFE has been also explored [21]. Gathak et al. proposed the use of alternative materials rather than PVDF, PTFE being fabrics such as PU or PP [26] obtaining a high filtration efficiency. Then, the idea of monitoring breathing such as [6,8,24] is mostly based on adding a TENG in the mask, based on now common triboelectric materials such as PTFE materials. In this field, we propose the use of fabrics due not only to their breathability, but also their friendliness with human skin, aesthetic design and biocompatibility.

These results are not only competitive with current state-of-the art, but also bring new approach for safe-design face mask. It should be mentioned that there is also the possibility of assembling the whole face mask with the fabrics studied in this work (cotton fabric and UHMWPE) in which, with the addition of the corresponding virus-filtration layers, could provide and effective protection against SARS-coV-2 and human breath monitoring.

Table 2: Relevant results concerning Triboelectric-assisted face mask systems over the last two years.

| Type of device | Materials/function | Textile-based | Monitoring (remote/local) | Reference |
|---|---|---|---|---|
| Face mask | Polyvinylidene fluoride (PVDF) | No | - | [46] |
| Smart textile face mask | PVC-nylon, polypropylene (PP)-Polyurethane (PU), latex rubber-PU, Polyimide(PI)-nylon | Yes | - | [26] |
| Triboelectirc air filter (TAF) | Polytetrafluoroethylene (PTFE) and nylon fabrics | Partially | - | [21] |
| Breathing monitor with acrylic TENG | Common facemask with a TENG | No | Local | [6] |
| Breathing and coughing monitoring via Bluetooth. | Al/PCB (printed circuit board) TENG. Bluetooth | No | Local/remote | [4] |
| Breath monitoring | Diatom bio-silica as a biomaterial additive to enhance the output performance of cellulose nanofibril (CNF) | Partially | Local | [8] |
| Breath monitoring | Ag-based nanofibers | Partially | Local | [50] |
| Monitoring breathing with CNTs | Hybrid carbon nanotubes(CNT)/ silk fibroin (SF) | Partially | Local | [24] |

| | | | | |
|---|---|---|---|---|
| Smart triboelectric face mask with breath monitoring, alarm and long rate | UHMWPE, Cotton | Yes | Local and remote | This work |

## Conclusions

To conclude, we successfully designed a smart, low-cost, all-fabric triboelectric nanogenerator face mask, with a warning system alarm which detects the absence of breathing and a long-rate monitoring control. This is possible due to the proper selection of materials carried out for this face mask such as UHMWPE and cotton fabric, which is not only simple but also environmentally friendly. The triboelectric effect is triggered due to the movement of the human breath inside the facemask, which in absence of such movement can turn into a local alarm system used to advice of the lack of breathing. In order to monitor remotely human breathing, LoRa communication protocol was used. In addition, studying the frequency and pulse shape we can also monitor not only the human breathing, but also other symptoms of respiratory diseases such as cough. This information can be not only stored locally and displayed, but also send via the IoT to other devices on real time, which can ensure the safety of multiple patients at distances of 20km far away from the receptor.  In case Wi-Fi is used, a shorter distance can be reached (about 2 km) and this configuration was tested too.

## CRediT authorship contribution statement

Antonio Vázquez-López: Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization. José Sánchez del Río: Methodology, Investigation, Formal analysis, Visualization, Writing – review & editing. Jimena de la Vega Formal analysis, Visualization.

Xiang Ao: Writing – review & editing. De-Yi Wang: Conceptualization, Writing – review & editing, Supervision.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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