

Transient Battery-Free Microphone-Integrated Face Mask

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Summary:

We introduce a transient, battery-free intelligent face mask for cough acoustic monitoring in pulmonology. It integrates a flexible passive microphone with a 3×3 membrane array coupled with a patch antenna, converting cough-induced vibrations into shifts in the electromagnetic reflection coefficient measured in zero-span mode. Fabricated from laser-patterned cellulose acetate, poly(lactic acid), and zinc, and stacked via a solvent- and adhesive-free low-temperature lamination process, the system enables detection of various cough intensities in humans, with over 90% degradation within 100 days.

Keywords: Smart face mask, Transient electronics, Green manufacturing, Patch antenna, Cough acoustics sensing

Background, Motivation and Objective

Cough is a fundamental early symptom of respiratory disease, and its acoustic characteristics—such as frequency, amplitude, and spectral features—offer a non-invasive and diagnostically specific modality for disease assessment [1]. Recent advances in wearable technologies have enabled continuous monitoring of respiratory health through chemical (e.g., volatile organic compounds in exhaled breath), physiological (e.g., respiratory rate, tidal volume), and acoustic signals. However, chemical sensing approaches are often limited by cross-sensitivity to environmental and metabolic factors, while physiological metrics lack specificity due to variability induced by non-respiratory conditions [2]. In contrast, cough acoustics provide event-driven signatures with high diagnostic specificity and robustness. Despite these advantages, existing wearable and mask-based systems predominantly rely on active microphones and bulky, non-biodegradable electronics powered by batteries that require periodic replacement, thereby limiting user compliance and scalability while exacerbating electronic waste [3]. Accordingly, this work aims to develop a scalable, battery-free, and biodegradable platform for continuous cough acoustic monitoring, leveraging sustainable materials and environmentally responsible fabrication processes. This abstract presents

preliminary results from our platform, as part of our recent work [4].

Description of the New Method or System

To address the need for scalable, sustainable cough-monitoring technologies, we introduce a biodegradable passive acoustic sensing system integrated into a single-use face mask. In contrast to conventional battery-powered, non-biodegradable mask-based systems, the proposed device performs acoustic sensing via a membrane-coupled patch antenna, in which sound-induced vibrations modulate the antenna's electromagnetic reflection coefficient. The system is fabricated entirely from sustainably sourced materials using a green manufacturing approach that combines laser processing with thermal lamination, enabling scalable production of fully biodegradable sensing devices.

Results

The device was fabricated using CO₂ laser machining ($\lambda = 10.6 \mu\text{m}$) followed by stepwise thermal lamination. Zinc (Zn, 10 μm), polylactic acid (PLA, 50 μm), and cellulose acetate (CA, 25–500 μm) films were laser patterned; the Zn as antenna conductor (patch and ground) was cut at 50 W and 1 cm/s (see Fig. 1a). Aligned layers were stacked using alignment marks and laminated between Teflon sheets. A 25 μm CA membrane was first bonded to a 100 μm CA base at

150 °C. The antenna stack (PLA/CA/Zn) was then laminated at 120 °C, above the PLA glass transition temperature ($T_g = 50\text{--}65\text{ °C}$), ensuring strong bonding. The PLA (50 μm) layer served as an encapsulating lamination pouch. The resonator was assembled using 100 μm PLA spacers to realize the final membrane-integrated patch antenna device (see Fig. 1b). The final device was integrated into a PLA-based surgical face mask (Fig. 1c).

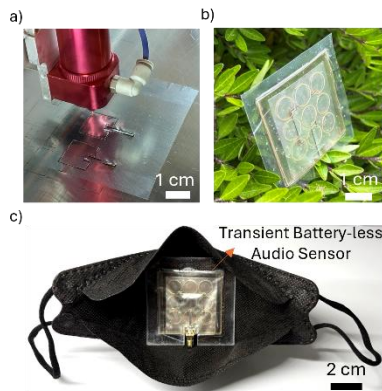


Fig. 1. a) Laser cutting of Zinc foil. b) Assembled device. c) Smart face mask integrated with a patch antenna-based device.

The dimensions of the patch antenna and acoustic resonator were optimized in CST Microwave Studio under face mask size constraints to achieve resonance at $\sim 6\text{ GHz}$.

Figure 2 shows the membrane response under 500 Hz acoustic excitation. The setup (Fig. 2a) uses a loudspeaker to excite the cellulose acetate membrane and a confocal sensor to measure the membrane displacement. The time-domain signal (Fig. 2b) shows three bursts, each reaching a peak displacement of $\sim 11\text{ }\mu\text{m}$. The Fast Fourier Transform (FFT) (Fig. 2c) exhibits a dominant peak at 500 Hz, which matches the sound frequency. The Short-Time Fourier Transform (STFT) (Fig. 3d) confirms sustained oscillation at 500 Hz with weaker harmonics at $\sim 1\text{ kHz}$.

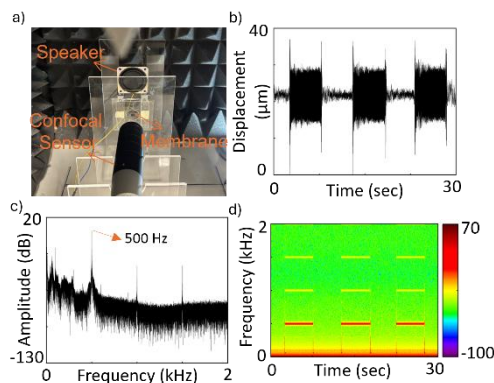


Fig. 2. a) Measurement setup. b) Time-domain displacement plot. c) FFT peak at 500 Hz. d) STFT spectrogram showing 500 Hz with harmonics (intensity in dB).

and $\sim 1.5\text{ kHz}$, indicating nonlinear excitation. The lower displacement at lower frequencies reflects viscoelastic, mass-controlled behavior, with increasing damping at higher frequencies.

Figure 3a presents the STFT spectrogram of the reflection coefficient ($|S_{11}|$) recorded in zero-span mode using a vector network analyzer (VNA), capturing real cough events. Distinct STFT signatures differentiate cough severity: mild ($<200\text{ Hz}$, low intensity), moderate ($\sim 300\text{ Hz}$), and severe (broad, high-intensity spectrum up to $\sim 600\text{ Hz}$). Industrial composting was simulated using water-saturated compost soil with controlled moisture and gas flow (see Fig. 3b). The PLA-based mask half embedded in soil fully degraded within 20 days, while the device lost $\sim 90\%$ of its weight after 100 days (Fig. 3c).

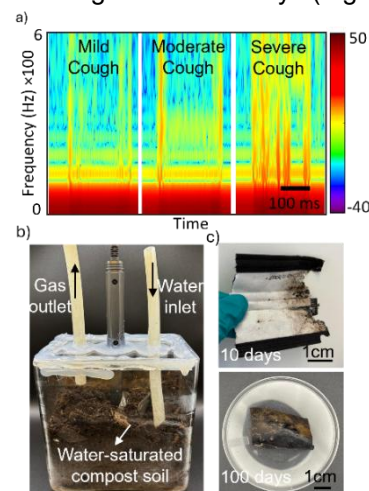


Fig. 3. a) STFT of $|S_{11}|$ (zero-span mode) showing mild, moderate, and severe cough signatures (intensity in dB). b) Industrial composting setup. c) Degradation of the facemask and device in soil.

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