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Rapid Detection of Linalool Using Solidly Mounted Resonators for Plant Health Monitoring

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Summary:
This paper presents the detection of VOCs by functionalised solidly mounted resonators (SMRs) for plant health monitoring. Two designs of SMRs have been developed, one by the University of Warwick (UWAR) and the other by Sorex Sensors Ltd. These were coated with ethyl cellulose and tested for a response to linalool – a plant pest biomarker. Both sensors show strong responses, with sensitivities of 1.03 kHz/ppm (UWAR) and 15 kHz/ppm (Sorex). While the Sorex sensor exhibited higher sensitivity, it had a slower response time. In contrast, UWAR SMR responded within 45 sec and showed higher resolution. Results highlight the potential of SMR sensors for rapid and accurate plant health monitoring.

Keywords: piezoelectric sensor, VOC detection, plant health, SMRs

Background, Motivation and Objective

Plants emit different volatile organic compounds (VOCs) as part of their defense response to insect herbivory, i.e. pests. One such compound, linalool, is a widely occurring monoterpene known for its ecological role in both repelling herbivores and attracting natural enemies of pests. Its emission is often triggered or elevated during pest attacks, suggesting the potential as a biomarker for early pest detection.

Conventional pest monitoring methods are labour intensive and often fail to detect infestations in their early stages. In contrast, monitoring VOCs through cost-effective, and compact smart sensors offer a non-invasive, real-time approach to crop health monitoring. Various crops, such as maize (*Zea mays*), tea (*Camellia sinensis*), tobacco (*Nicotiana tabacum*), and chrysanthemum (*Chrysanthemum morifolium*), are known to release linalool when attacked by herbivorous insects. However, achieving fast, accurate, and selective detection of emitted linalool traces remains a significant challenge [1, 2].

This work introduces a custom 3D-printed chamber designed for the simultaneous detection of linalool using two SMRs (UWAR and Sorex), integrated with a commercial temperature and humidity sensor (Bosch BME280). Both SMRs were functionalised with ethyl cellulose, were tested in the presence of linalool diluted in air and exhibited a rapid, strong, and selective response.

Materials and methods

The UWAR and Sorex SMR devices used in this study are shown in Figures 1(a) and 1(b), respectively. The UWAR device was designed in the laboratory and fabricated at SilTerra (Malaysia) using a combined CMOS-MEMS 180 nm process. The fabricated SMR has overall dimensions of 1.0 mm × 2.5 mm, with a VOC sensing area of 500 µm × 351 µm. A solution of ethyl was spin-coated onto the top surface of both SMRs to form a sensing layer.

Fig. 1 shows microscopic images of the EC-coated SMRs. Although the deposited layer is very thin (<100nm) and transparent, making it difficult to observe directly, the light reflections produce varying colours on the surface, confirming successful deposition of the thin film.

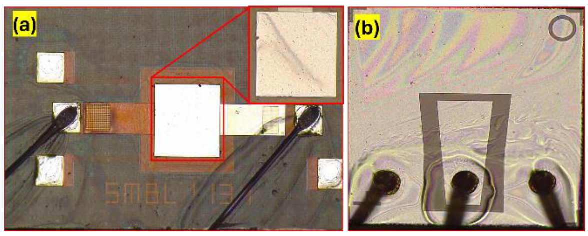

Fig. 1. EC coated SMRs, (a) UWAR SMR, inset show the magnified image of the sensing area, and (b) Sorex SMR.

After depositing the sensing film, both SMRs were installed in the 3D-printed chamber, as shown in Fig. 2. This chamber was designed to enable simultaneous monitoring of both SMRs in the presence of linalool, while continuously

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tracking ambient temperature and humidity levels using the BME280 sensor.

A Keysight VNA, integrated with a customized NI LabVIEW program, was used to monitor frequency shifts over time. The VOC flow through the sensing chamber was precisely regulated using fully automated mass flow control system.

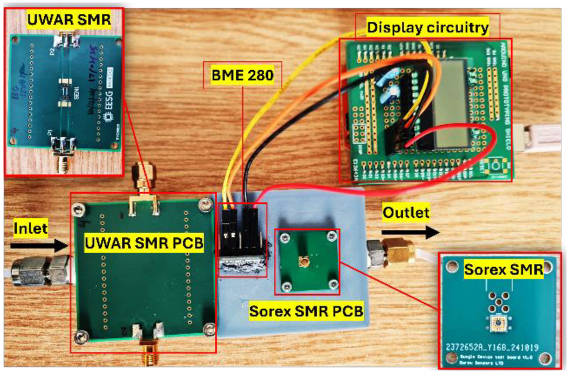

Fig. 2. 3D printed chamber (grey) with both SMRs, inset shows the front side of UWAR and Sorex sensors.

Results and Discussions

The SMR devices are highly sensitive to environmental changes, particularly temperature and humidity. To account for this, a BME280 sensor was installed inside the chamber to monitor both parameters throughout the experiment. It was observed that the frequency of the UWAR SMR decreases with increasing temperature, whereas the frequency of the Sorex SMR increases under the same conditions. Significant baseline drift was observed in both sensors. To compensate for this, a linear temperature compensation model was applied:

$$f_{(t,c)} = f_m + k_T\ (\Delta T) \qquad (1)$$

Where $f_{(t,c)}$ is temperature compensated frequency, f_m is measured frequency, k_T is a constant, and ΔT is temperature change.

Figures 3(a) & 3(b) display the temperature-compensated responses of the UWAR and Sorex SMRs, respectively. The insets in each figure show the sensor responses before compensation, with arrows indicating the direction of baseline drift due to temperature fluctuations. The SMRs were tested with linalool at concentrations of 10, 5, and 1 ppm in dry air conditions. The UWAR SMR exhibited a faster response with higher resolution, while the Sorex sensor showed a stronger overall response but with a longer response time. Testing with higher concentrations of potentially intefering other plant biomarkers, namely trans-2-hexenal and ethanol, confirmed excellent selectivity to linalool. The UWAR SMR includes an integrated micro-heater and is undergoing further investigations to assess response at higher temperatures. This low-cost MEMS-based SMR technology has great potential as a non-invasive, real-time solution for plant health monitoring.

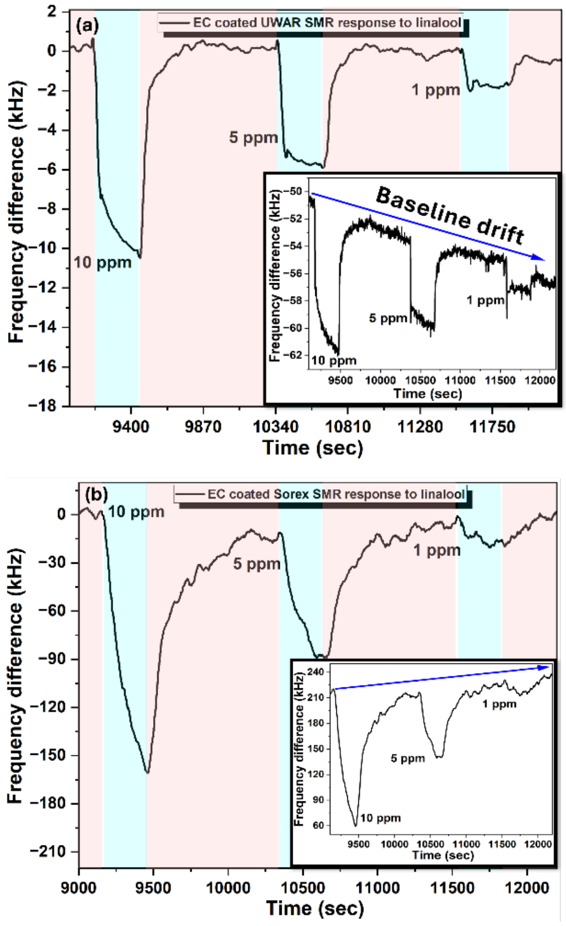

Fig. 3. Temperature compensated frequency shift vs. time responses of SMRs to PPM levels (a) UWAR SMR, and (b) Sorex SMR.

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