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Applicability Assessment of a Thermo-Formed Piezoelectret Accelerometer in Agricultural Robotics Systems

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Igor Nazareno Soares

Igor Nazareno Soares graduated in computer engineering at University of São Paulo (USP), Brazil, and received the master’s degree in electrical engineering from USP in 2020. MBA in business administration and in agribusiness, he is currently a doctoral student majoring in electrical engineering at the Engineering School of São Carlos, University of São Paulo.

His research interest lies in sensor development and applications, energy harvesting, business administration, financial markets, and education.

1. Objective and contributions

The **aim of the work** is to evaluate the **applicability** of a **custom-developed Thermo-Formed Piezoelectret Accelerometer (TFPA)** for use in **agricultural robotic systems**.

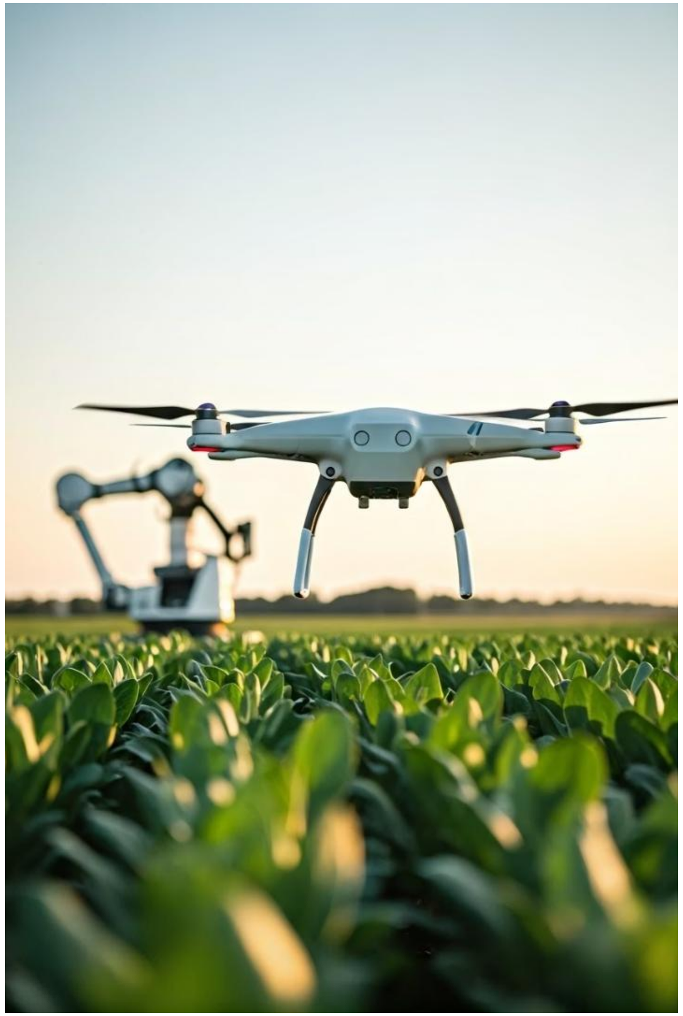
More specifically, the study seeks to:

- Determine whether the TFPA can **reliably measure vibrations** in environments typical of agricultural machinery and robotics (e.g., UAVs, harvesters, robotic arms).

From the **experimental characterization** of the sensor's frequency response and sensitivity:

- Develop and validate an **analytical dynamic model** (mass–spring–damper system) to predict and tune the sensor's behavior.
- Analyze the **compatibility** of the sensor with real-world vibration profiles in agriculture.
- Explore the potential for **mechanical tuning** and **application-specific customization**.
- Ultimately, the goal is to propose a **cost-effective, robust, and tunable sensor** suitable for embedded vibration monitoring in precision agriculture.

2. Introduction



Agricultural Robotics

Autonomous Tractors

Advanced efficiency in farming operations

Robotic Arms

Precision harvesting and handling

UAVs

Monitoring and spraying applications

3. Piezoelectret Accelerometers

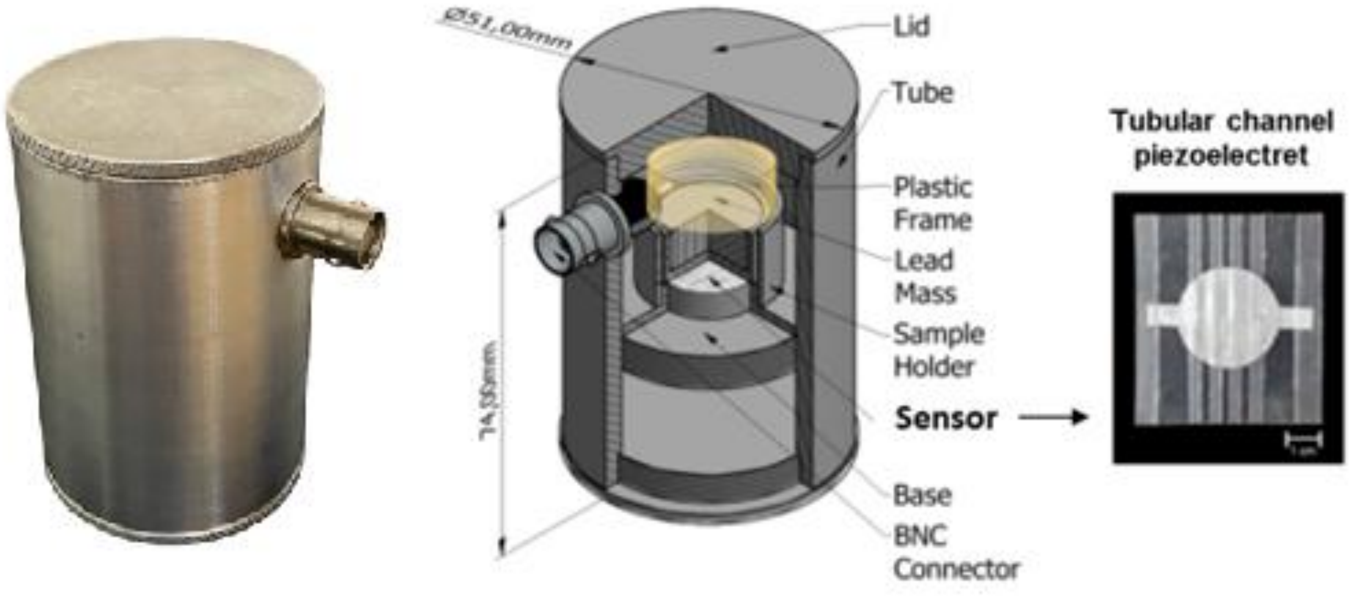
Accelerometer principles

- Mass
- Sensing Mechanism
- Reference Frame
- Measurement of Displacement or Deformation
- Conversion to Output Signal
- Signal Processing and Output

Piezoelectret Accelerometers

- Polymeric materials advantages over traditional piezoelectric materials
- New piezoelectret material: thermo-formed piezoelectrets (Altafim et al., 2009)

4. Experimental details



(a) (b) (c)

Figure 1. (a) Constructed TFPA prototype (b) TFPA internal structure (c) Piezoelectret sensor with open tubular channels

4. Experimental details

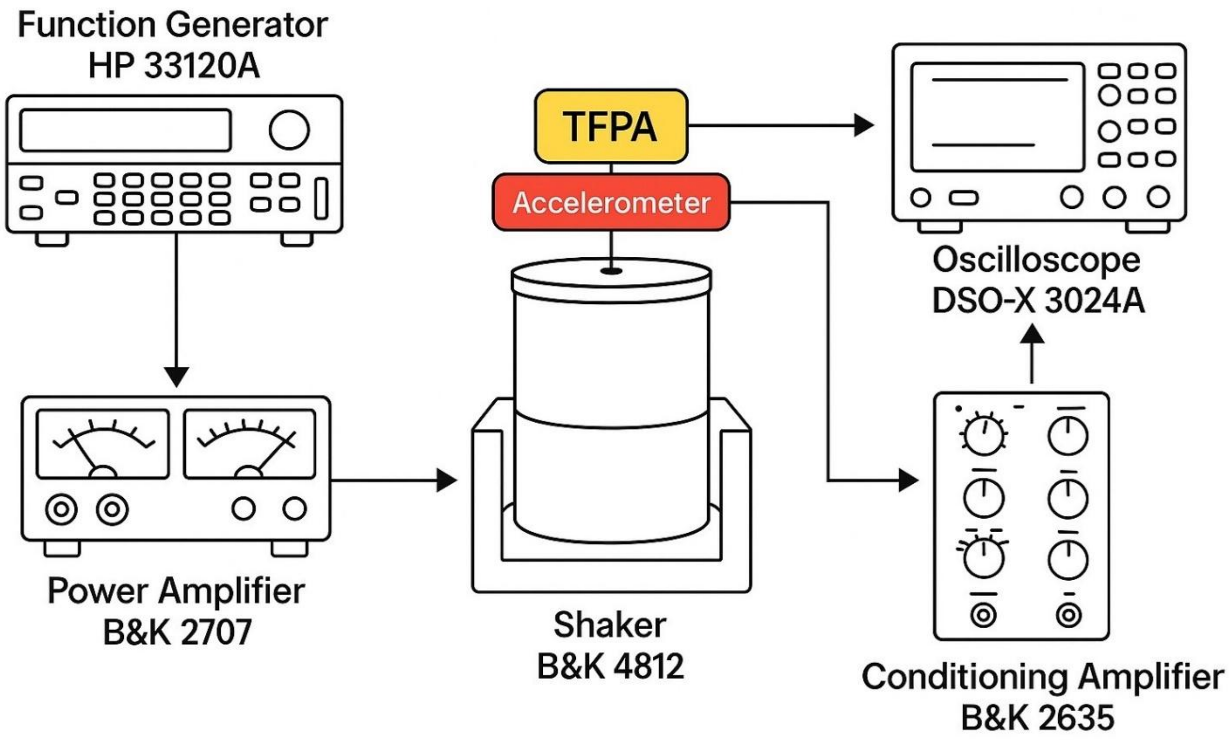


Figure 2. Standard electrodynamic vibration setup for the TFPA tests.

5. Results and discussion

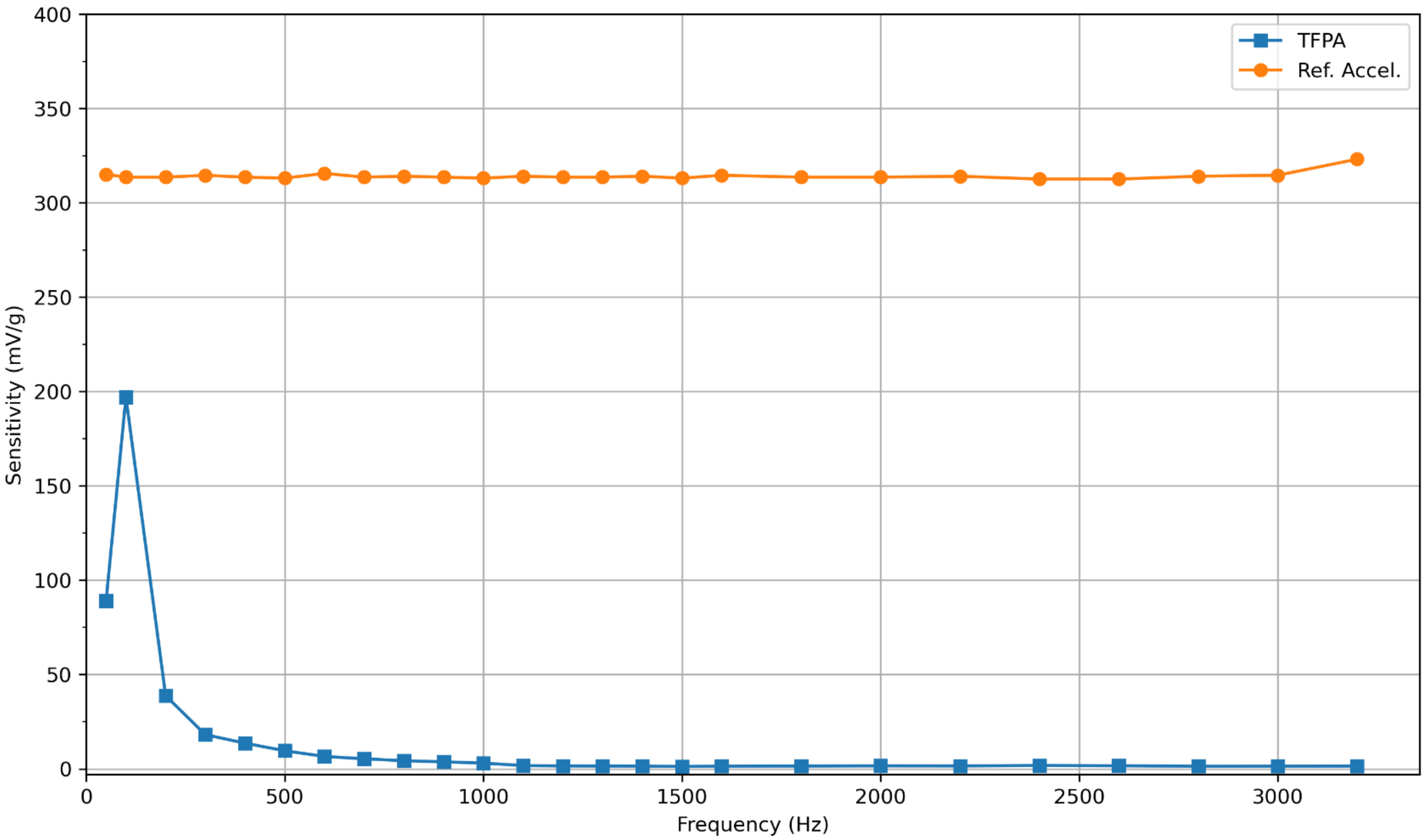


Figure 3. Frequency response of the TFPA, with a resonance frequency at 100 Hz

5. Results and discussion

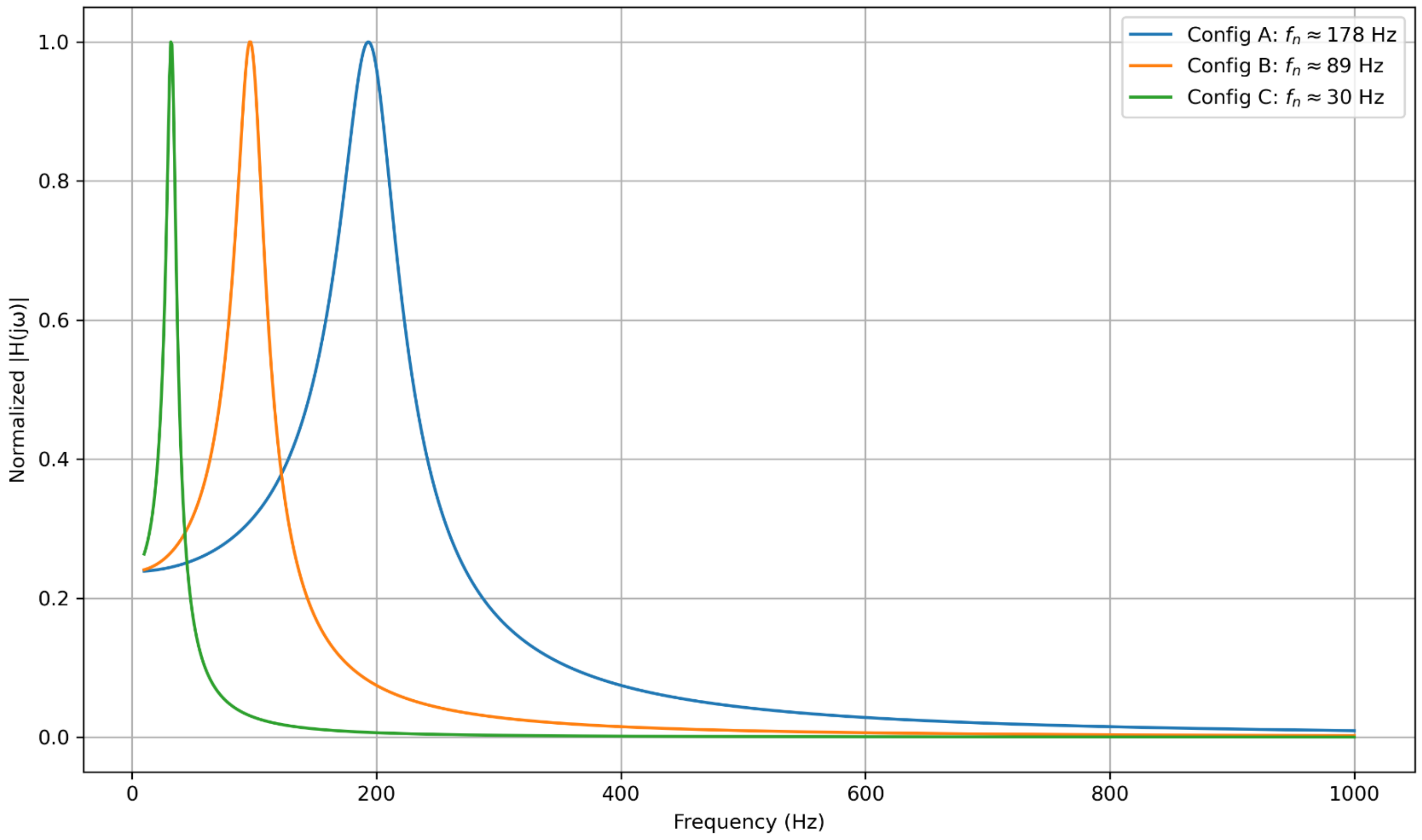


Figure 4. Simulated frequency responses for configurations A, B, and C, illustrating resonance tunability via changes in mass, stiffness, and foam thickness

5. Results and discussion

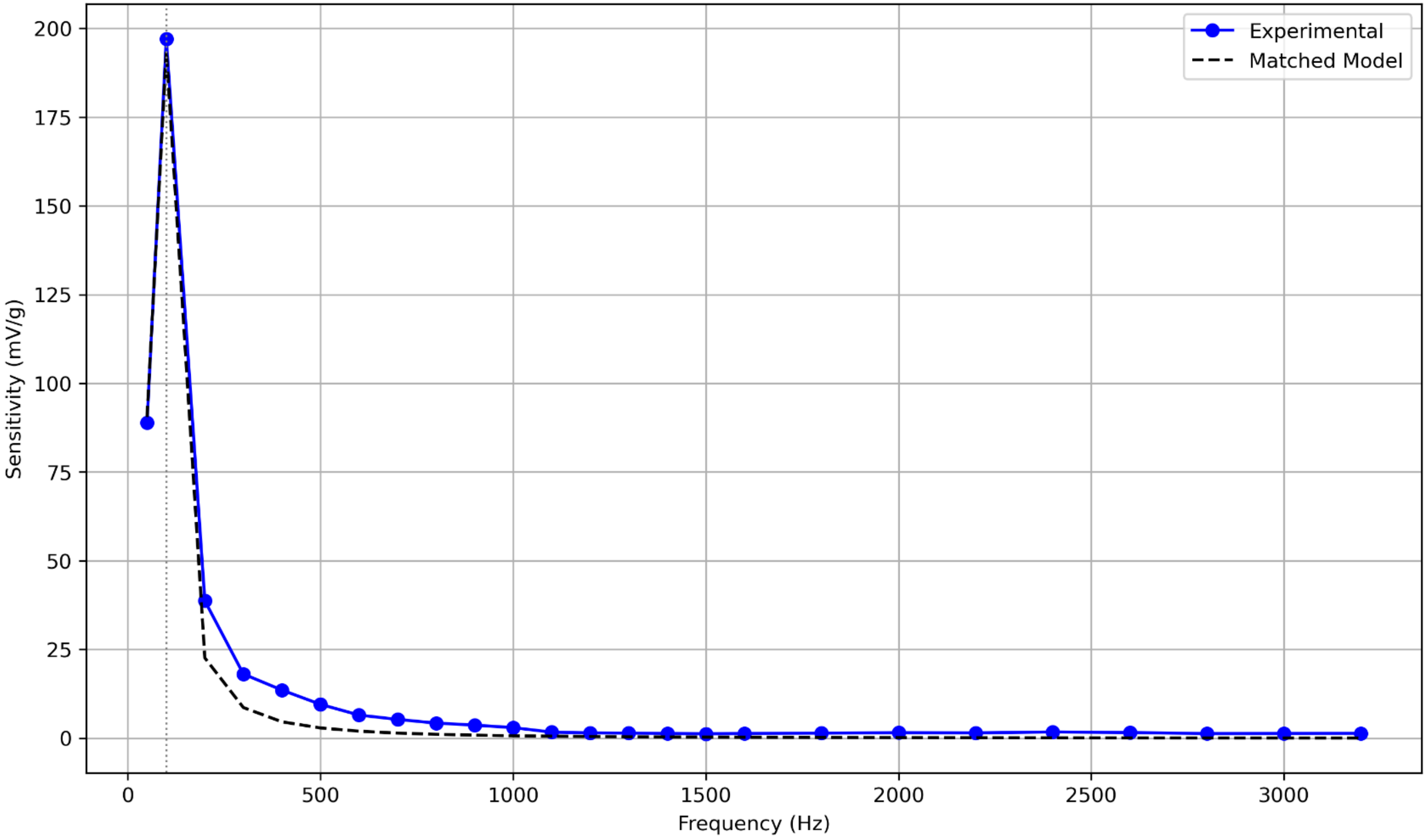


Figure 5. TFPA response comparison: experimental sensitivity data and matched simulation in physical units

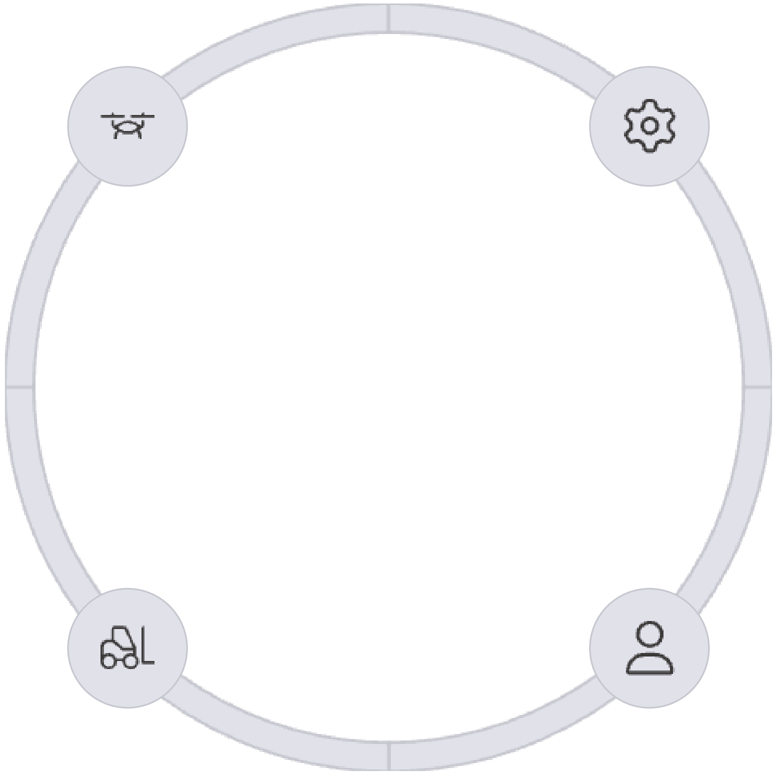
Application Compatibility

UAVs (70-230 Hz)

Excellent match with sensor's resonance

Gearboxes (250-1000 Hz)

Usable with signal amplification



Harvesters (10-35 Hz)

Needs tuning for optimal sensitivity

Robotic Arms (4-40 Hz)

Requires parameter adjustment

6. Conclusion and future work

Conclusion:

- The TFPA was successfully designed, calibrated, and modeled for agricultural robotics applications.
- The sensor showed a peak sensitivity of ~196 mV/g at 100 Hz, behaving like a second-order underdamped system.
- The experimental frequency response matched well with the analytical mass–spring–damper model, confirming the accuracy of the simulation approach.
- The TFPA is suitable for mid-frequency applications (e.g., UAVs, electric motors) and remains functional at higher frequencies with amplification.
- The sensor’s resonance and bandwidth can be tuned by adjusting the seismic mass, foam thickness, and material stiffness.
- Despite its current size, the TFPA has strong potential for miniaturization and integration into compact robotic platforms.
- The TFPA is a promising, low-cost, customizable solution for embedded vibration sensing in precision agriculture.

Future work:

- Miniaturization
- integration of electronics
- field testing and extending calibration to lower frequencies (<50 Hz).

Thank you!

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