Acoustic Volumeter

version 1.0

An open-source, DIY, microphone-free acoustic volumetry platform for rapid, precise volumetric measurements—designed for global phenotyping applications.

Contents

Overview

Acoustic Volumeter v1.0 is a Python-based freeware implementing the microphone-free acoustic volumetry method described by Haghshenas & Emam (2025). By measuring shifts in the resonance peak of a sealed chamber fitted with a dynamic microphone cartridge, the software enables rapid, accurate volume estimation down to single-grain scales.

Hardware Requirements

The Acoustic Volumeter v.1.0 is a freeware tool designed to work in tandem with a simple DIY hardware setup. While the software handles all acoustic signal processing and modeling tasks, it relies on audio signals captured via an external hardware probe.

Instructions for building the required hardware — using affordable and easily available components — are provided in the accompanying manuscript. Please refer to the paper for circuit details, assembly steps, and calibration considerations.

Additionally, Acoustic Volumeter can be adapted to other sensor configurations—for example, systems with separate excitation (speaker) and recording (microphone) units or multi-sensor arrays.

Software Requirements

- **Cross-platform:** Windows, macOS, and Linux
- **Python:** 3.8 or newer (only needed if running from source)
- **Dependencies (source install):**
  pillow, numpy, scipy, matplotlib, sounddevice, pandas

Installation

Option A: Pre-built Executable (Windows)

1. Download the latest ZIP from
   https://github.com/haqueshenas/Acoustic-Volumeter
2. Unzip **AcousticVolumeter.zip**
3. Run **AcousticVolumeter.exe** — no further setup required.

Option B: From Source

```
git clone https://github.com/haqueshenas/Acoustic-Volumeter.git
cd Acoustic-Volumeter
pip install -r requirements.txt
```

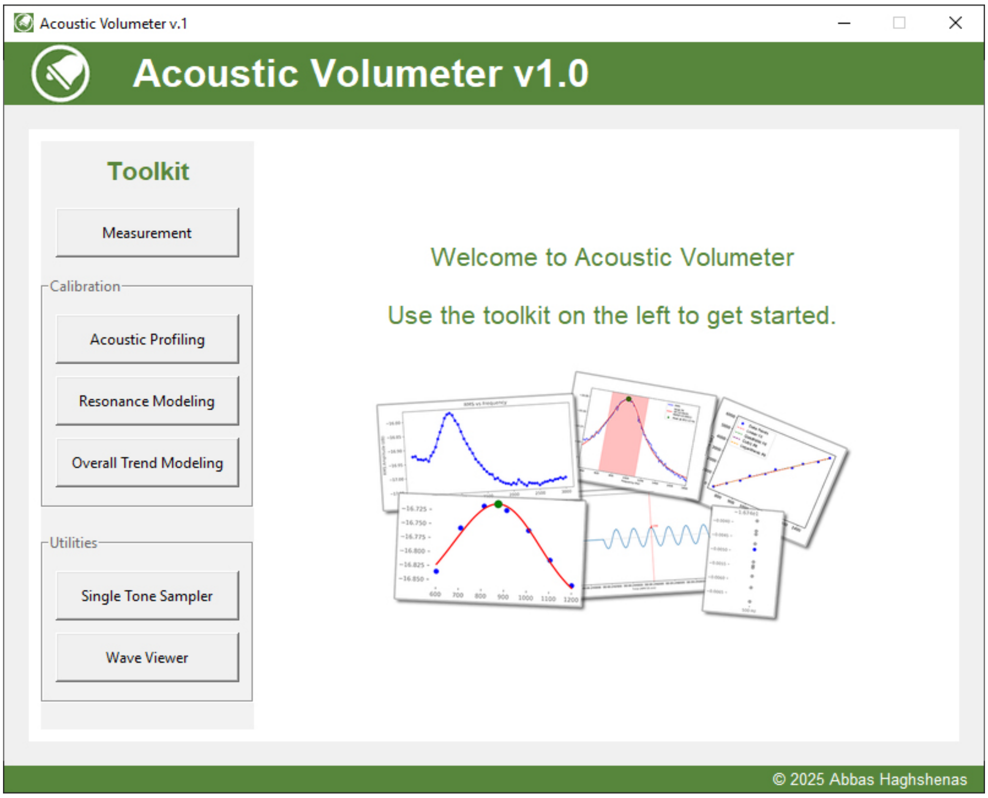
Option C: Run individual modules in Python

```
python measurement.py        # Measurement
python profiling.py          # Acoustic Profiling
python r_modeling.py         # Resonance Modeling
python overall_trend.py      # Overall Trend Modeling
python single_tone.py        # Single Tone Sampler
python wave_viewer.py        # Wave Viewer
```

Note: All modules require Python 3.8+ and the same dependencies listed in Option B if you're running from source.

Tools at a glance

Use the left-hand menu in the main window to launch any of these tools (modules) in its own dedicated interface.



- Measurement
  Direct volumetry using calibrated peak-fit (EST) and overall-trend models.
- Calibration:
  - Acoustic Profiling
    Frequency-sweep RMS profiling of your sensor to build calibration data.
  - Resonance Modeling
    Curve-fit analytical models (Gaussian, Lorentzian, Voigt, etc.) to extract peak parameters.
  - Overall Trend Modeling
    Regression fits (linear, quadratic, cubic, logarithmic, piecewise) mapping resonance frequency → volume.

- Utilities:
  - Single Tone Sampler
    Play/record a single sine tone for quick device checks and RMS metric gathering.

- ### Wave Viewer
  Interactive multi-file WAV browser with zoom, pan, timeline slider, and hover annotations.

Quick Start Guide:

Follow these six simple steps—each launching a different module—to go from a blank lab bench to a calibrated, accurate volume measurement.

System Audio Setup

Once the sensor is connected to the sound card (see the M&M section of the paper), ensure that microphone playback is muted by checking both the operating system settings and the sound card control panel.

⚠ **Safety First:** Always begin with very low playback levels (e.g. 0.005–0.01). Exceeding your sound card's or amplifier's normal operating range can permanently damage your hardware. Use the *Acoustic Profiling* or *Single Tone Sampler* tool to verify input/output levels before running any full sweep.
• Mute system sounds or disable "Listen to this device" in your OS audio settings to avoid feedback.

• Disable or suppress any operating system notification sounds during experiments.

• Select and test your input/output devices in the *Acoustic Profiling* module.

If this is your first time using the sensor, proceed to the calibration steps. Acoustic Profiling will help map your sensor's acoustic response.

1. Acoustic Profiling

This module maps your sensor's raw RMS versus frequency, generates device_config.json, and saves a sweep (CSV/PNG/WAV) for the next fitting step.

If you're trying the Acoustic Volumeter for the first time, follow these steps:

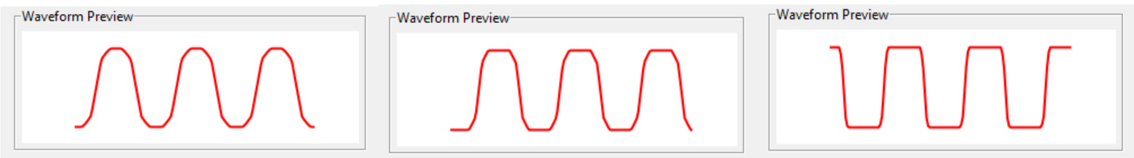
Step 1: In the Preparation frame, detect and select the correct output (e.g. headphones) and input (microphone) devices. After selecting each device, test it using the provided options.

Step 2: With devices set, configure the Playback Settings and click Run. If you're unsure about initial values, start with defaults and an empty chamber. A clear sinusoidal waveform should appear, and a distinct resonance peak should be visible in the main plot. If the frequency range or amplitude is insufficient, adjust them—gradually increase amplitude (e.g. from 0.005 to 0.01) until you achieve a clear resonance peak. Repeat as needed to optimize profiling.

Below are example waveforms recorded under various conditions:

Standard amplitude (normal sinusoidal waveform):

Exceeded amplitude:



Low-level amplitude:

Step 3: After profiling completes, a pop-up will prompt you to save outputs. Save the CSV file; it will be used in Resonance Modeling.

Repeat Steps 1–3 for each calibration sample (up to 10, including an empty chamber) to collect all required output sets.

2. Resonance Modeling

This module curve-fits each sweep to cleanly extract the chamber's resonance peak, producing a JSON file of model parameters and peak frequency.

For resonance modeling, follow these steps:

Step 1. Open a CSV file generated by Acoustic Profiling.

Step 2. If the data include the full resonance convexity, select the best-fitting model and click Apply. Otherwise, use trimming tools (frequency limits or percentile trimming) to isolate the full peak range before fitting.

Step 3. Once you find the best fit, click Export to save the Resonance Modeling outputs (JSON model specification). This file will be used in Overall Trend Modeling.

Repeat these steps for each calibration condition.

3. Overall Trend Modeling

This module builds the frequency→volume calibration curve by fitting peak frequency versus known volume, yielding a JSON calibration file for Measurement.

For overall trend modeling, follow these steps:

Step 1. Load each JSON file from Resonance Modeling and enter the exact volume of the corresponding calibration object (from lowest to highest, up to 10 samples). You can save and reload the complete list for future use.

Step 2. Click Fit and review the results. Adjust data or volumes and refit as needed.

Step 3. When satisfied, click Export to save the Overall model JSON.

Calibration is now complete. Use this JSON in the Measurement tool to estimate volumes of unknown objects. Unless you alter the sensor assembly, sound card, or ambient conditions significantly (e.g., temperature/humidity), this calibration remains valid.

4. **Measurement**
   Apply your calibration live: play/record the sweep, find the peak, compute unknown volumes, and save results.

   For volumetry of an unknown object:

   - Place it in the sensor chamber.
   - Set playback properties (informed by your Acoustic Profiling) and click Run.
   - After the sweep, a clear resonance convexity should appear; optionally trim unwanted data to refine peak detection.
   - Select your EST (peak estimation) model and the Overall Trend Model JSON file.
   - Click Save to record measurement results.

Utilities

5. **Single-Tone Sampler** to sanity-check a single frequency's RMS.
   This module can also support other studies (e.g. RMS-based volumetry methods reported by previous researchers; see the paper for details).

6. **Wave Viewer** to inspect and annotate any WAV recordings.

Tools in Detail

Measurement

The Measurement module is the core utility of Acoustic Volumeter v.1.0 used for estimating object volumes based on resonance shifts.

<u>Key Features</u>

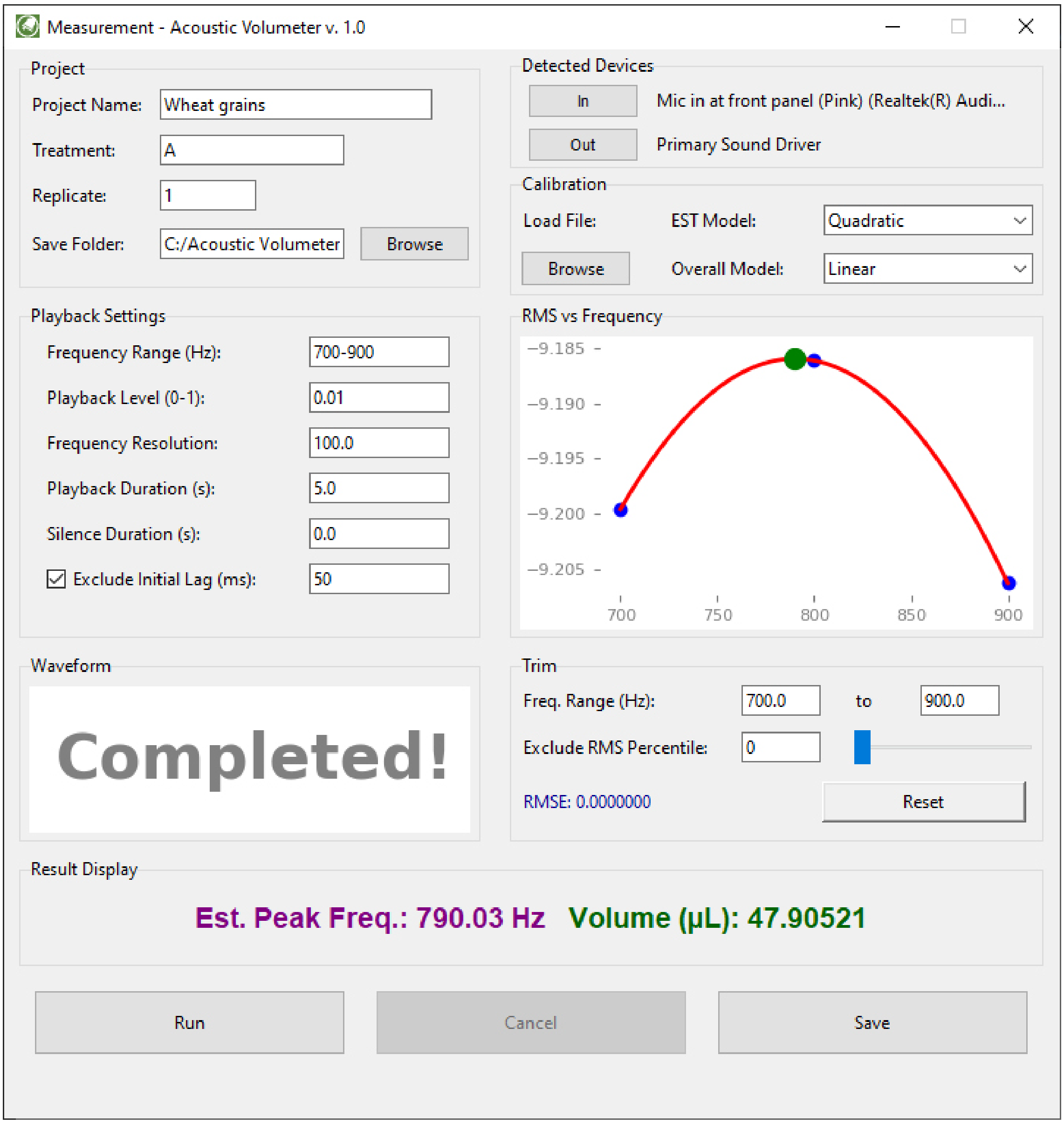
- **Project Frame**: Name, Treatment, Replicate + "Browse" for save folder (auto-creates subfolders).
- **Calibration Panel**:
  - Load JSON calibration file

    - Choose EST model (None/Quadratic/Gaussian/Lorentzian/Asymm. Lorentzian/Voigt)
    - Choose overall trend (Linear/Seg-Linear/Quadratic/Cubic/Logarithmic)
- **Detected Devices**: View & swap input/output via dropdowns.
- **Playback Settings**:
    - Frequency range, level, resolution, durations (tone / silence), initial-lag exclusion
- **Waveform Display**: Live 3-cycle snippet centered on current tone.
- **RMS vs Frequency Plot**:
    - Scatter of RMS (dB) vs Hz
    - Fit overlay & peak marker
    - Span selector for trimming
    - Percentile slider for outlier exclusion
    - Auto-computed RMSE
- **Result Display**: Estimated peak (Hz) and volume (μL).
- **Actions**:
    - **Run** (with remaining-time countdown)
    - **Cancel** (marks “Canceled!”)
    - **Save** → PNG/WAV/CSV (with all metadata)

<u>Workflow</u>

1. **Setup Project**
    - Fill in project/treatment/replicate and pick a save folder.
2. **Load Calibration**
    - Click “Browse” to import your JSON model, pick EST + Overall trend.
3. **Check Devices**
    - Verify input/output in the Detected Devices box; use “In”/“Out” to change if necessary.
4. **Configure Playback**
    - Enter frequency range, level, resolution, durations, and lag exclusion.
5. **Run Measurement**
    - Click **Run** (or Ctrl + Enter) to sweep; watch waveform & RMS plot update in real time.
6. **(Optional) Cancel**
    - Press **Cancel** or Esc to stop early and see “Canceled!” on the plot.
7. **Save Results**
    - Click **Save** (or Ctrl + S) to export:
        - High-res RMS plot (PNG)

- Full recording (WAV)
- Summary CSV (project info, device, settings, peak & volume)



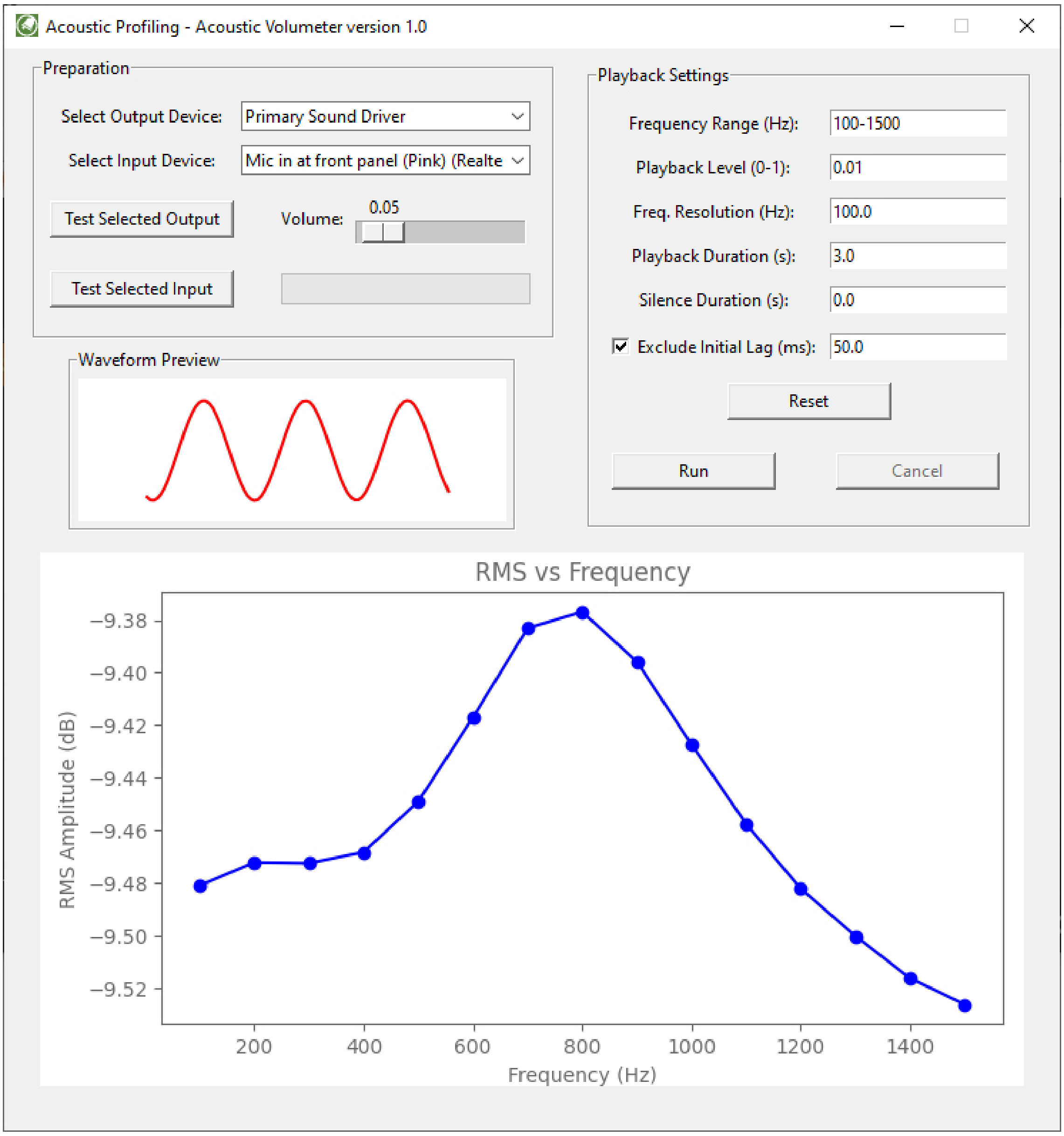
Hotkeys

Shortcut	Action
Ctrl + Enter	Run measurement
Ctrl + S	Save results
Esc	Cancel measurement

Calibration tools

Acoustic Profiling

Generate and record a frequency sweep to profile the sensor's RMS response.



<u>Key Features</u>

- **Device Prep**: select and test input/output devices; adjustable test-tone volume.
- **Sweep Settings**: frequency range, playback level (0–1), resolution, tone duration, silence duration, and optional lag trimming.

- **Real-Time Preview**: waveform segment and RMS vs. frequency plot updating live, with status bar showing current frequency and remaining time.
- **Cancellation**: abort mid-sweep and display “Canceled!” on the plot.
- **Data Export**: on completion, save CSV, PNG, WAV, and a detailed log TXT.

<u>Workflow</u>

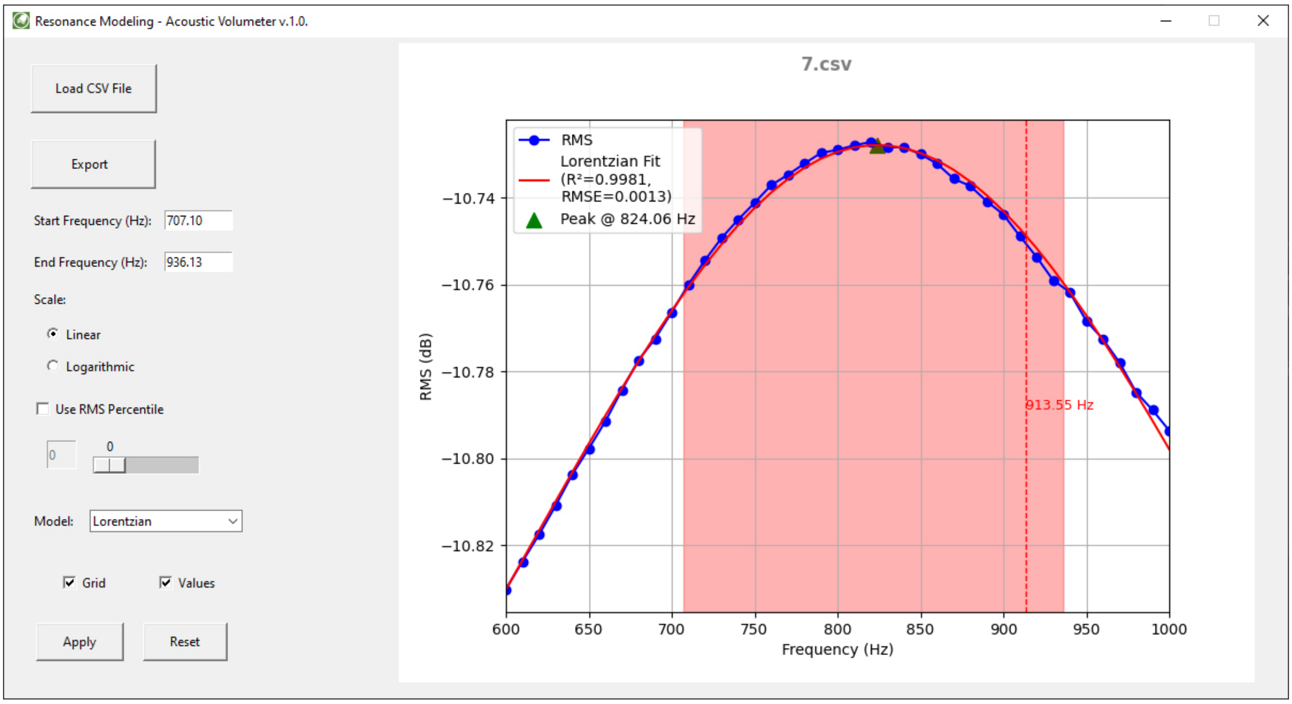
1. **Preparation**
    - Choose **Output Device** / **Input Device** from dropdowns.
    - Click **Test Selected Output** to play a 1 kHz tone; use **Volume** slider to adjust.
    - Click **Test Selected Input** and clap—progress bar shows microphone level.
2. **Configure Sweep**
    - **Frequency Range**: min–max (e.g., 100-3000).
    - **Playback Level**: amplitude (0–1).
    - **Freq. Resolution**: step size in Hz.
    - **Duration** & **Silence**: seconds per tone and pause.
    - **Exclude Initial Lag**: checkbox + ms entry.
3. **Run / Cancel / Reset**
    - **Run**: begin sweep; plot animates with blue markers.
    - **Cancel**: stops sweep, shows “Canceled!”.
    - **Reset**: restores defaults.
4. **Save Results**
    - Prompt asks for base filename.
    - Saves:
        - <name>.csv (Frequency vs. RMS)
        - <name>.png (RMS plot)
        - <name>.wav (entire recorded signal)
        - <name>_log.txt (device settings, timestamps, lag info, detected peak)

Hotkeys

Shortcut	Action
Ctrl + Enter	Run Sweep
Ctrl + R	Reset Parameters
Esc	Cancel Sweep

Resonance Modeling

Fit analytical models to the RMS-vs-Frequency convexity and extract peak parameters.



Key Features

- **Load CSV**: import a two-column file (Frequency (Hz), RMS (dB)).
- **Scale Controls**: switch X-axis between linear and log.
- **Range Selection**:
  - Manually enter **Start/End Frequency** or
  - Drag over plot to select a span.
- **Percentile Filter**: checkbox + slider/entry to exclude the bottom X% of RMS values.
- **Model Selection**: choose between Quadratic, Gaussian, Lorentzian, Asymmetric Lorentzian, or Voigt.
- **Visual Toggles**: show/hide grid and value-marker (hover displays frequency + vertical line).
- **Apply & Reset**: re-compute the fit on the selected range or revert to full data.
- **Export**: save high-res PNG plus a JSON file containing:
  - Model name & coefficients
  - Estimated peak frequency & amplitude
  - RMSE of the fit

Workflow

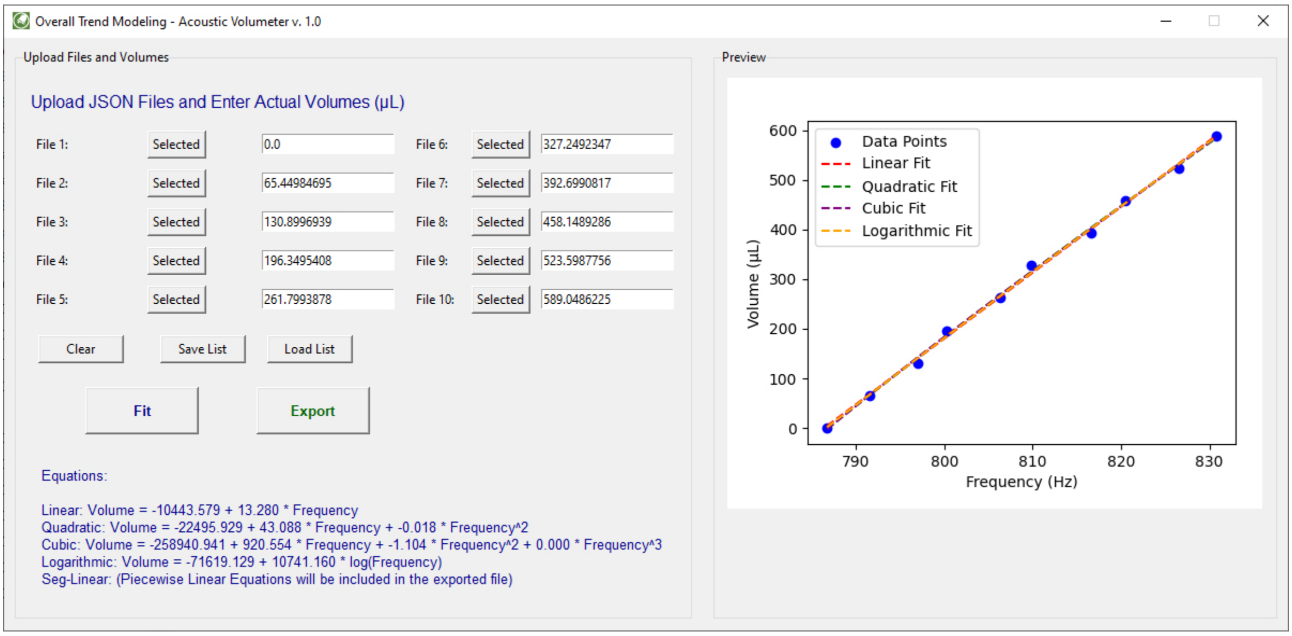
1. **Load Data**
   - Click **Load CSV File**.
   - File must include Frequency (Hz) and RMS (dB) columns.
2. **Set Range & Filters**
   - Enter **Start/End Frequency** or drag over the plot to highlight.
   - (Optional) check **Use RMS Percentile** and set threshold to filter out low-amplitude noise.
3. **Choose Scale & Display**
   - Select **Linear** or **Logarithmic** scale.
   - Toggle **Grid** and **Values** (hover tooltips).
4. **Select Model**
   - Pick one of: Quadratic, Gaussian, Lorentzian, Asymmetric Lorentzian, or Voigt.
5. **Apply Fit**
   - Click **Apply**:
     - Computes curve fit over the filtered span.
     - Overlays red fit line, green peak marker, and displays R^2 & RMSE.
6. **Reset**
   - Click **Reset** to restore original data range, clear overlays and filters.
7. **Export**
   - Click **Export**, choose a base filename.
   - Saves:
     - <base>.png (plot at 600 DPI)
     - <base>.json with model parameters, peak, and RMSE.

Overall Trend Modeling

Derive calibration curves mapping resonance-peak frequency to known sample volumes.

Key Features

- **Multi-Point Input**: Load up to 10 JSON files exported by Resonance Modeling.
- **Volume Entry**: Enter the corresponding actual volume (μL) for each file.



- **List Management**:
  - **Clear**: reset all selections.
  - **Save List**: export file-path & volume pairs to CSV for later reuse.
  - **Load List**: import a previously saved CSV.
- **Regression Fits**: upon **Fit**, computes:
  - **Linear**
  - **Quadratic** (2nd-degree polynomial)
  - **Cubic** (3rd-degree polynomial)
  - **Logarithmic** (V = a·log(F) + b)
  - **Seg-Linear** (piecewise linear between each consecutive data point)
- **Equations Display**: shows formulae and coefficients in the UI.
- **Preview Plot**: scatter of (Frequency, Volume) with overlaid fit curves, legend.
- **Export**:
  - **Export** button opens save dialog:
    - <base>.json containing all model coefficients.
    - <base>.png high-resolution plot image.

Workflow

1. **Upload & Label**

    - Click **Browse** next to each “File n” to select its JSON (contains Estimated Peak → Frequency).
    - Enter the known sample volume (μL) beside each file.
2. **Optional List Save/Load**
    - **Save List**: dump current file-path + volume table to CSV.
    - **Load List**: repopulate fields from a saved CSV.
3. **Fit Models**
    - Click **Fit**:
        - Reads each JSON to extract its resonance peak.
        - Gathers paired arrays of frequencies and volumes.
        - Performs regressions, overlays each fit on the plot.
        - Updates the **Equations** panel with human-readable formulae.
4. **Export Results**
    - Click **Export**, choose a base filename.
    - Saves .json with all regression coefficients, and .png of the plot.

Utilities

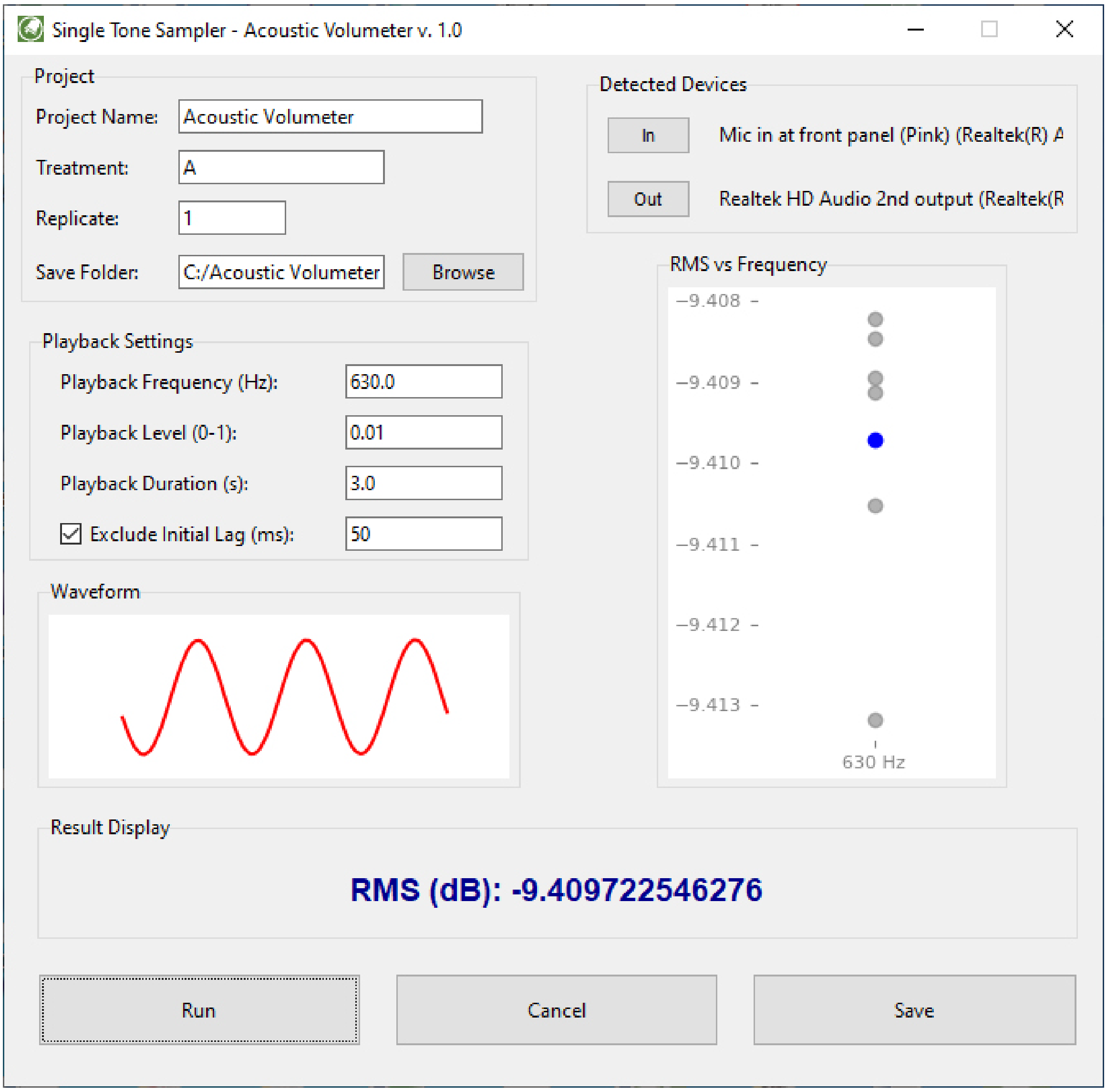
Single Tone Sampler

A lightweight utility for generating and recording a single sine-wave tone to verify device performance and gather RMS metrics.

<u>Key Features</u>

- **Project Metadata**: enter Project Name, Treatment, Replicate, and Save Folder.
- **Device Display & Selection**: shows saved input/output audio devices; “In”/“Out” buttons let you change them.
- **Playback Settings**:
    - **Frequency (Hz)**: single tone frequency (default 500 Hz).
    - **Level (0–1)**: amplitude of the tone (default 0.005).
    - **Duration (s)**: playback and record length (default 5 s).
    - **Exclude Initial Lag (ms)**: checkbox + entry to trim early samples.
- **Waveform Preview**: plots three cycles at the center of the recorded waveform (red, axes off).
- **RMS Display & History**:

- Shows the most recent RMS (dB) in the **Result Display**.
- Historical RMS points on the **RMS vs Frequency** canvas—current in blue, previous in grey.
- Right-click the RMS plot to **Clear** history; or press **Ctrl + R**.



- **Save Results**: exports:
  - Plots/<Project>_<Treatment>_<Rep>.png (RMS plot)
  - wav/<Project>_<Treatment>_<Rep>.wav (recorded tone)
  - <Project>.csv log with metadata, tone settings, and RMS.

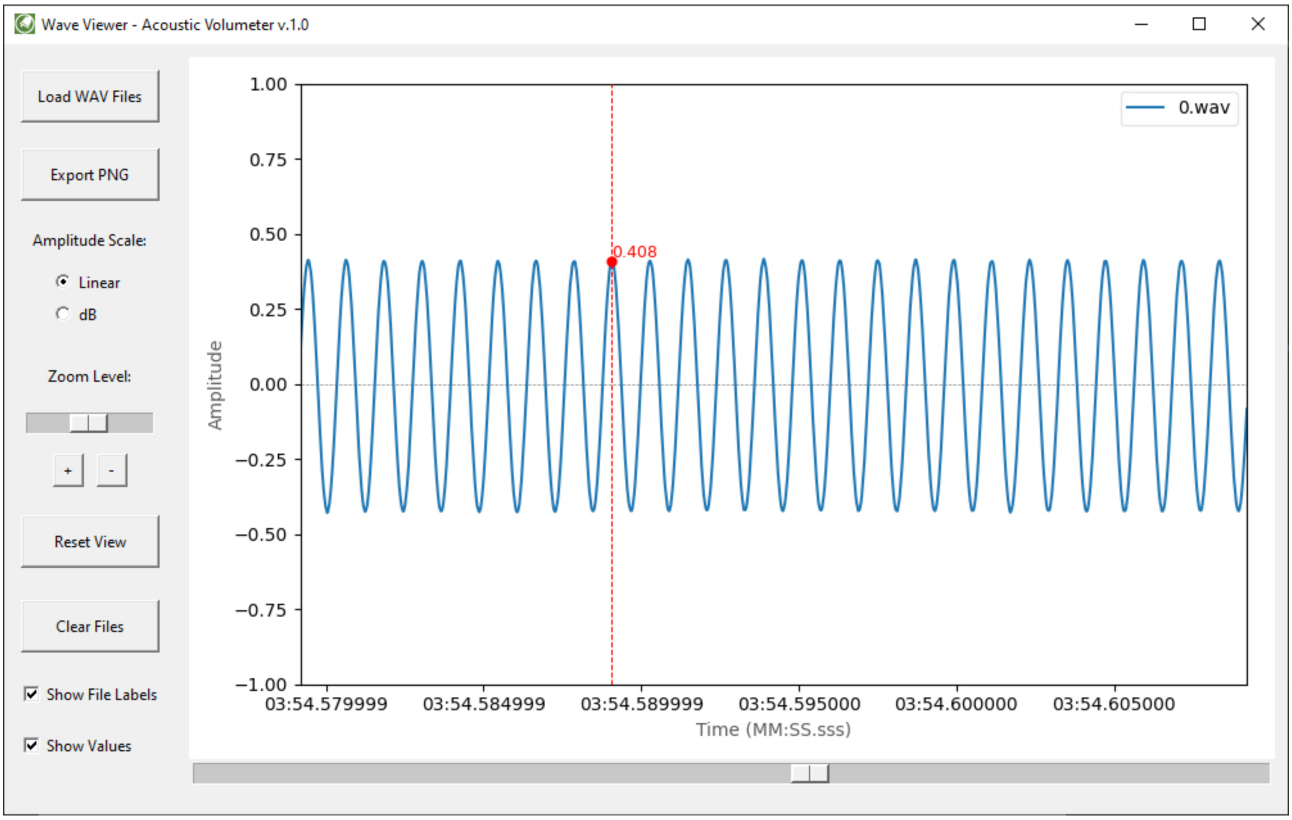
Workflow

1. **Setup**: enter project info and save folder; verify or change devices.
2. **Configure Tone**: set playback frequency, level, duration, and optional initial-lag exclusion.

3. **Run / Cancel**: click **Run** (or press Ctrl + Enter) to play/record; **Cancel** or Esc to abort.
4. **Clear History**: right-click RMS plot, choose **Clear plot**.
5. **Save**: click **Save** (or Ctrl + S) to export plots, audio, and CSV.

Wave Viewer

An interactive browser for .wav recordings, supporting multiple files, zoom, pan, and annotation.



Key Features

- **Load / Drag-and-Drop**
  - Click **Load WAV Files** or drag & drop up to **8** .wav files into the window.
- **Multi-Panel Display**
  - Each file is shown in its own subplot, stacked vertically, sharing the time axis.
- **Amplitude Scale**

- Radio buttons to switch between **Linear** (–1 to +1) and **dB** (–120 to 0 dB) scales.
- Zoom & Pan
  - **Mouse wheel** or **± buttons** to zoom in/out.
  - **Zoom slider** (logarithmic mapping) for fine control.
  - **Arrow keys** (Up/Down) to adjust zoom.
  - **Click-and-drag** on plot to pan horizontally.
- Timeline Slider
  - Below the plot, drag to scroll through the recording; Left/Right arrows also move it.
- Hover Annotations
  - When **Show Values** is checked, moving the mouse over a waveform displays:
    - A red marker at the nearest sample.
    - A vertical dashed line at that time.
    - A tooltip showing the amplitude value.
- File Labels
  - Toggle **Show File Labels** to display or hide each subplot's legend.
- Export / Reset / Clear
  - **Export PNG**: save the current multi-waveform plot.
  - **Reset View**: revert zoom and pan to full duration.
  - **Clear Files**: unload all files and reset the canvas.

Workflow

1. **Load** files via the button or drag & drop.
2. **Toggle** amplitude scale (Linear/dB).
3. **Zoom** with wheel, slider, buttons, or Up/Down keys.
4. **Pan** by dragging or moving the timeline slider.
5. **Hover** for instantaneous amplitude readings (if enabled).
6. **Export** the composite wave-plot as PNG.
7. **Reset** or **Clear** to start over.

Configuration & Persistence

- **device_config.json / singletone_config.json**
  Remember selected audio input/output devices.
- **measurement_config.json**
  Remembers last-used project settings, playback parameters, and selected models.

Citation

If you use Acoustic Volumeter in your research, please cite:

Haghshenas A. & Emam Y. (2025). *Reimagined Microphone-Free Acoustic Volumetry: An Open, DIY Platform for Global Phenotyping.* bioRxiv.

Disclaimer

Use Acoustic Volumeter at your own risk. The developers make no warranty of any kind, express or implied, including but not limited to merchantability, fitness for a particular purpose, or non-infringement. In no event shall the authors or copyright holders be liable for any claim, damages or other liability arising from the use of this software.

Warning:
Please take special care not to exceed the standard input/output ranges of your sound card, amplifier, or custom circuitry. High playback amplitudes, improper amplifier settings, or mis-wiring can damage your hardware or computer. Always start with low levels (e.g. 0.005–0.01) and verify each component under the *Single Tone Sampler* or *Acoustic Profiling* tool before running full sweeps.

License

About This Tool

This software is part of the **Easy Phenotyping Lab (EPL)**—a non-profit initiative aimed at sharing open, affordable, and reliable computational tools for plant and crop phenotyping research. Visit https://haqueshenas.github.io/EPL for more tools and modules developed under VPL.

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