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Performing Near Field Acoustic Holography Scans for the Purpose of Finding the Acoustic Impedance of a Violin

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INTRODUCTION

Acoustic impedance is important when considering the violin and musical instruments in general since it is indicative of the performance of the instrument [1]. By mapping out its values on the violin, there would emerge an enhanced level of understanding how sound creation works in the violin. Using near field acoustic holography (NAH) scans, the impedance of the violin can be mapped out. NAH requires in-phase and quadrature particle velocity and sound pressure values.

This is a summary of what was accomplished this semester and an outline for the measurements and analysis to follow.

Materials

- Instrument: violin
- Two magnets
- Transmit coil: to excite magnets
- Function generator
- Foam for string dampening
- XY-translation slides
- Three omnidirectional pressure microphones: Optimus 33-3013
- BNC cables
- Lock-in amplifier

Testing Frequency: Open A

Procedure:

- Place magnets on either side of the bridge
- Set up a Sound Sensor with data collection software
- Connect transmit coil to function generator
- Set generator to 440 Hz and place coil near magnets to excite them
- Collect sound intensity data with sound sensor while violin is producing sound
- Use the Fast Fourier Transform to analyze the frequencies produced

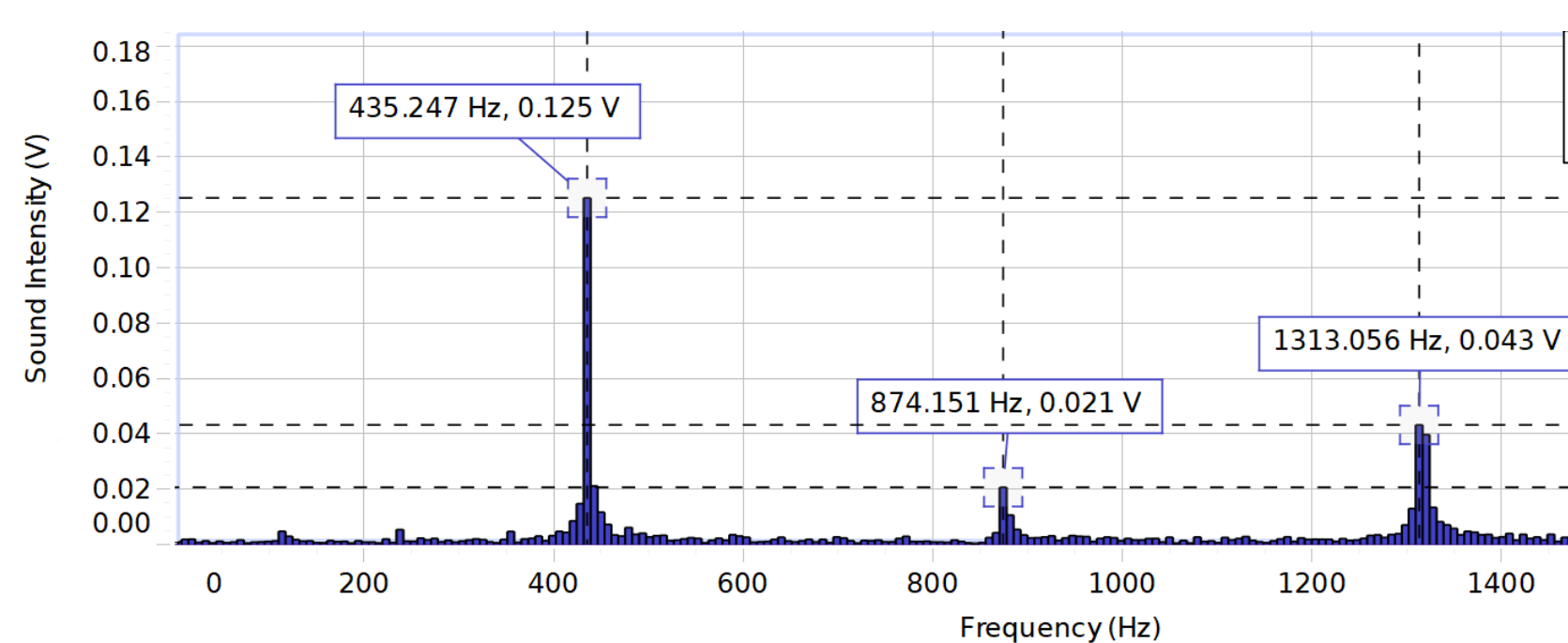


Figure 2: Measured Frequency

Confirmation that the violin was producing sound at 440 Hz from the excited magnets. The sound at approximately 440 Hz can be seen along with the next two harmonics which are expected to appear with a clear tone produced.

- Use lock-in to determine phase of the quantities
 - In-phase indicates real part
 - Quadrature part indicates the imaginary part
 - Allows quantifying of real and complex parts of pressure and velocity and calculating of complex impedance [3]
- As the coil is transmitting the frequency, collect data from the microphones in a 1 cm x 1 cm grid along the back plate.
 - Record data from all three microphones manually or using a data collection software.

Figure 1: Cartoon Model of Data Collection Set-Up

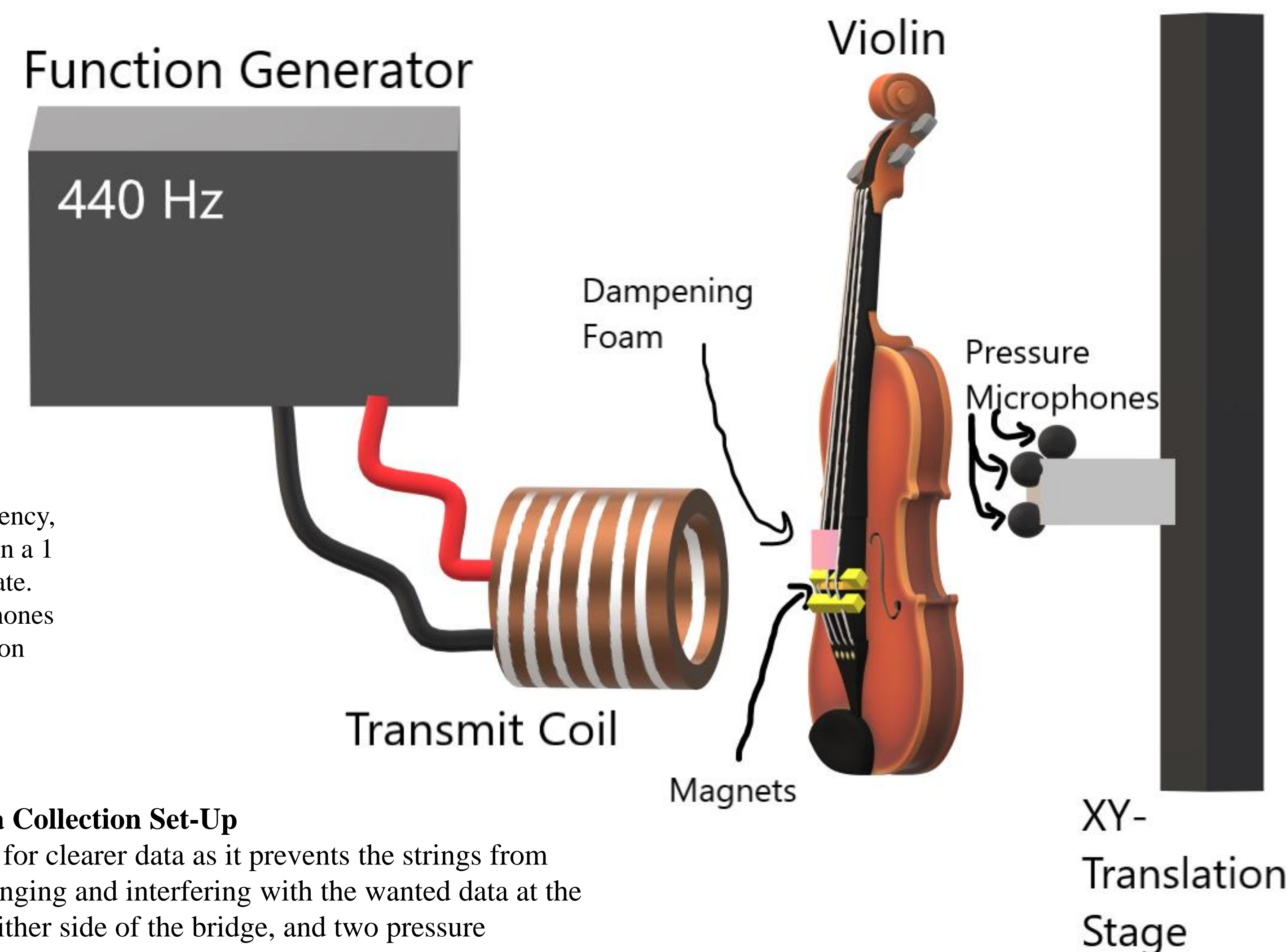
The foam dampens all four strings for clearer data as it prevents the strings from vibrating or any harmonics from ringing and interfering with the wanted data at the back plate. The magnets stick on either side of the bridge, and two pressure microphones sit facing each other approximately 1 cm apart. The other microphone sits facing the back plate of the violin. The violin should be suspended or held up by some support system [3].

To conduct the NAH scans, tests should be conducted at the resonance frequency/frequencies of the instrument since resonance frequencies provided the strongest vibration for the system, allowing for clearer data to be collected. The resonance frequencies of the violin strings are known to be the open G (196 Hz), D (294 Hz), A (440 Hz), and E (659 Hz) strings [3]. The body resonance of the violin is known to be approximately 440 Hz; this makes the open A a favorable testing frequency as it allows the largest signal to be detected. Prior to data collection, the frequency emitted from the violin due to the excited magnets was evaluated to ensure it was at the correct frequency. The harmonics at 440 Hz were also looked at to assess the quality of the sound produced.

Sources of Error

- Temperature and humidity of the air can have a significant effect on the wood of the violin and the values of acoustic impedance calculated [1].
- Since the edges of the violin are not flat, measurements there will have more error [3].
- Each violin will have slightly different resonance frequencies due to their architectural properties.
- Data collected at higher frequencies ($\approx \geq 650$ Hz) will have a decrease in imaging resolution [3].

SET UP



Acoustic Impedance (Z)

- The ratio of pressure (p) to particle velocity (U)
$$Z = \frac{p}{U}$$
- Describes the sound pressure created by vibrations at a certain frequency [4].
- Directly analogous to electrical impedance
- Pressure \rightarrow Voltage
- Particle Velocity \rightarrow Current
- Unit: $[\frac{\text{Pa}\cdot\text{s}}{\text{m}^3}]$
- Real and imaginary parts of acoustic impedance will be computed using measurements from the lock-in amplifier
- Real part: the resistance/part that propagates sound
- Imaginary part: the reactance/the non-sound propagation part.
- Complex parts are needed as the current and pressure of the sound are not necessarily in phase [4].

Computation

Pressure: The pressure is directly proportional to the electrical output of the microphone.

Particle Velocity: A pressure gradient is obtained from the two facing pressure microphones. The two microphones can be aligned parallel to the field of sound produced to obtain maximum pressure difference [2].

Using Newtons second law,

$$F = ma$$

the equation:

$$\frac{dp}{dx} = -\rho \frac{dU}{dt}$$

can be obtained where ρ is the density of the fluid, $\frac{dp}{dx}$ is the change in pressure over the known distance between the microphones, and $\frac{dU}{dt}$ is the change in particle velocity with respect to time [2]. This relationship exists because of Euler's Equation. Now integrate to solve for the particle velocity:

$$U = -\frac{1}{\rho \Delta x} \int (p_1 - p_2) dx$$

where p_1 and p_2 are the pressures measured at the two facing microphones and Δx is their known distance between them [2].

After calculating the two values for each point on the violin collected, acoustic impedance may be calculated using the relationship between p and U.

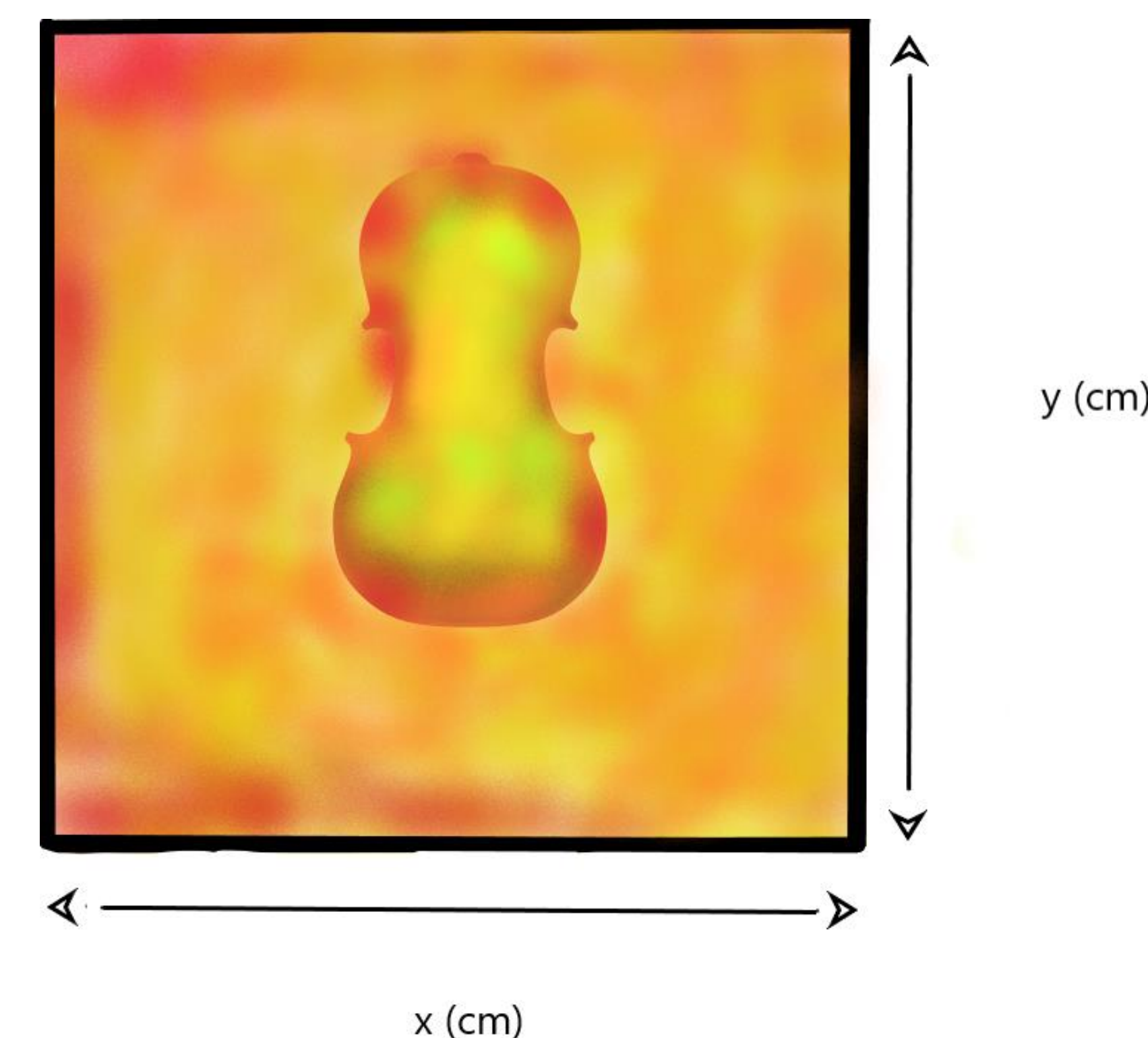


Figure 3: Cartoon Model of Acoustic Impedance Scan

This is an idea of what the results will look like after plotting all measurements of (real) acoustic impedance on each point (x,y) based off information from source [3] which performed these scans on a viola. Areas of red/orange have higher impedance while yellow and green have lower values. The outline of the violin is clearly visible.

Future Research

- Analyze a relationship between the sound post and the acoustic impedance in order to understand the effect the sound post has on the production of sound in a violin.
- Perform same tests on different models of violins.

[1] Johnson, E. (1981). The Acoustics of the Violin (Doctoral dissertation).
 [2] M. Long, Architectural Acoustics 129, 174 (2014).
 [3] Powell, M. 2012. Acoustic Analysis of the Viola .
 [4] R.H. Randall, An Introduction to Acoustics (Dover Publications, Newburyport, 2012).

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