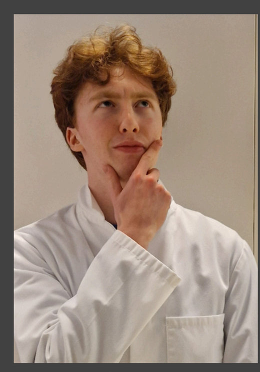
24 **Triangular Rods:**

Capturing Acoustic Patterns with an Acoustic Camera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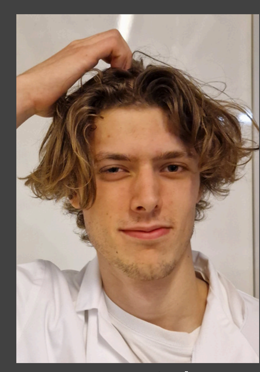
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1. Introduction

It can be derived mathematically that a triangle mostly vibrates at its end points (see QR code). We have tried to demonstrate this result experimentally using an acoustic camera (AC). The AC is a tool made up of a microphone array and a camera that is able to localize a sound and visualize it on a picture or video. This is where the AC has the advantage over the conventional approach where it is also able to visualize it.

2. Theory

An acoustic camera consists of an array of microphones, with a camera in the center (figure 1). It can be used to locate sound sources under two assumptions:

1. All microphones collect the same data if we ignore the phase-difference.
2. The sound radiated from the source can be interpreted as a plane wave, which is a fair assumption for $r \gg 2\lambda$, where r is the distance from the source to the AC and λ is the wavelength of the incoming soundwave [1].

Under these assumptions, we can use the difference in path length ($v\,\Delta t$) to calculate theta using formula 1, where $v\,\Delta t$ and Θ are as given in figure 3, this method is commonly known as time-based analysis.

$$\theta = \arccos\frac{v\Delta t}{d}$$

Formula 1: v = speed of sound (T=293K), Δt = time difference of arrival, d = distance between individual microphones.

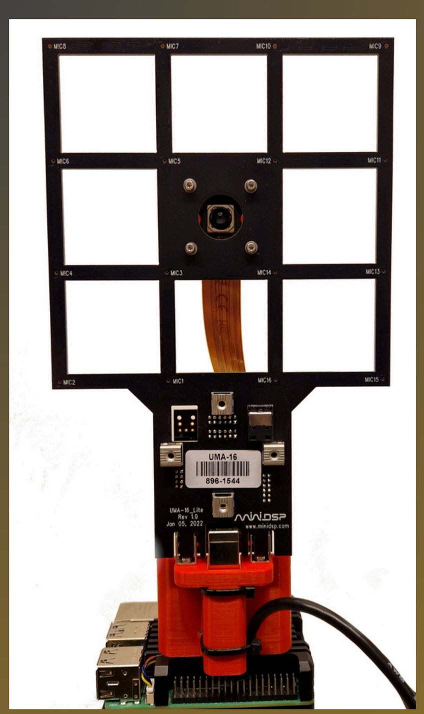
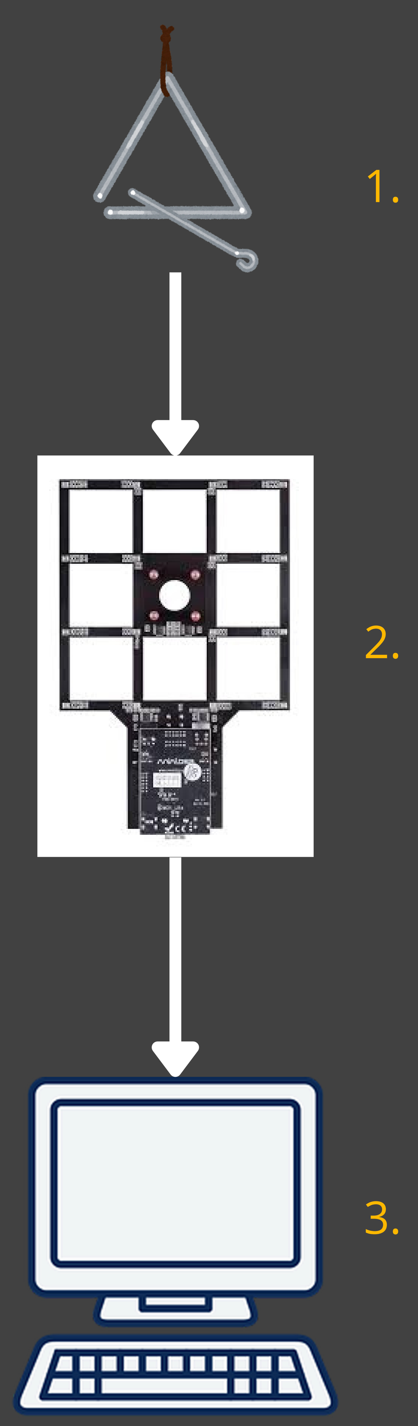


Figure 1: The AC we used: a miniDSP UMA-16 v2 microphone array and a Raspberry Pi Camera Module 3 Wide camera operated by a Raspberry Pi 5 computer. The microphones are 0.042 ± 0.001m apart.

3. Method

Figure 2: Test setup



1. The frequency spectrum of the triangle that will be used is shown in figure 4. The lowest frequency with a major spike is located at 1911Hz, which corresponds to a wavelength of 0.18m. Since all higher frequencies will have longer wavelengths, setting the AC and the source 0.90m apart allows us to use the second assumption that was mentioned in the theory section.
2. The AC that will be used is shown in figure 1. Audio will be detected at a sampling frequency of 44000Hz for a duration of 2 seconds. The picture will be taken at a resolution of 1920x1440.
3. Python collects the data of all 16 microphones and calculates the phase difference by use of the correlation function in the scipy.signal library. An average phase difference over the whole array is then determined, from which we can find the location of the source by use of formula 1. This location is then converted to pixel coordinates and shown in the picture. [2]

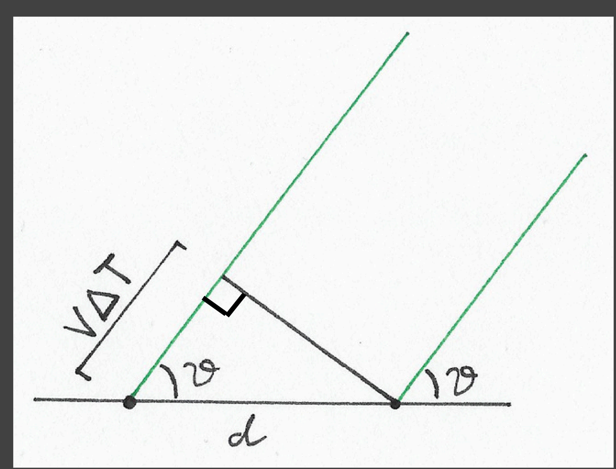


Figure 3: v Δt = difference in path length, *d* = distance between microphones, *Θ* = incoming angle

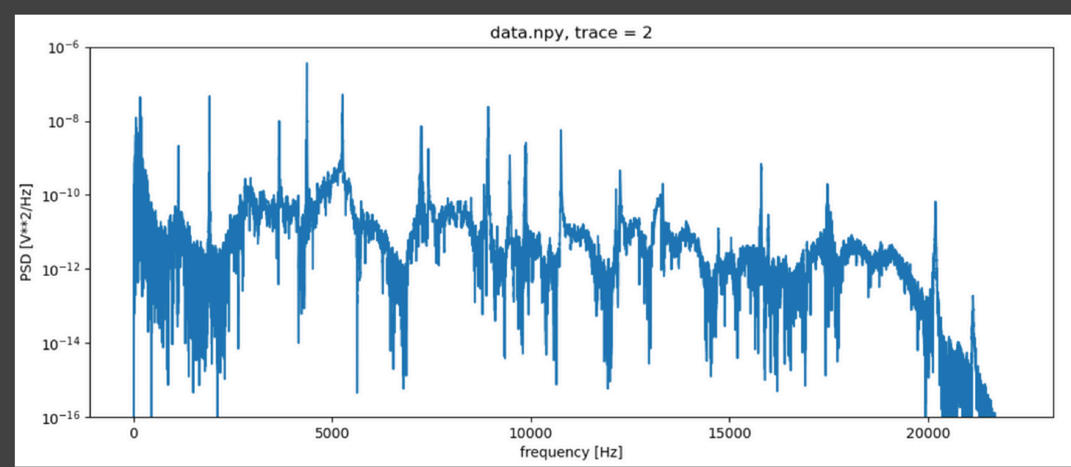


Figure 4: Spectrum of the used triangle instrument.

4. Results and Discussion

The sound source was localized at *insert pixel coords with error*. The error was propagated based on the error on the distance between the microphones of *insert err*, as well as an error on Delta t of 1/44000s. These results are shown in figure 5, which is a cropped version of the original figure.

There are three important discussion points:

1. Although the cross is located at one of the ends of the triangle, the error spans over the entire object, meaning that the resolution of our setup is too low to conclude anything meaningful.
2. Most of the measurements we did were heavily influenced by noise, often leading to impossible results or even no results at all. Since our measurements were inaccurate most of the time, it's possible that our final result is inaccurate as well.
3. It is possible that we measured the sound of the wooden hammer hitting the triangle, rather than the vibrations of the triangle.

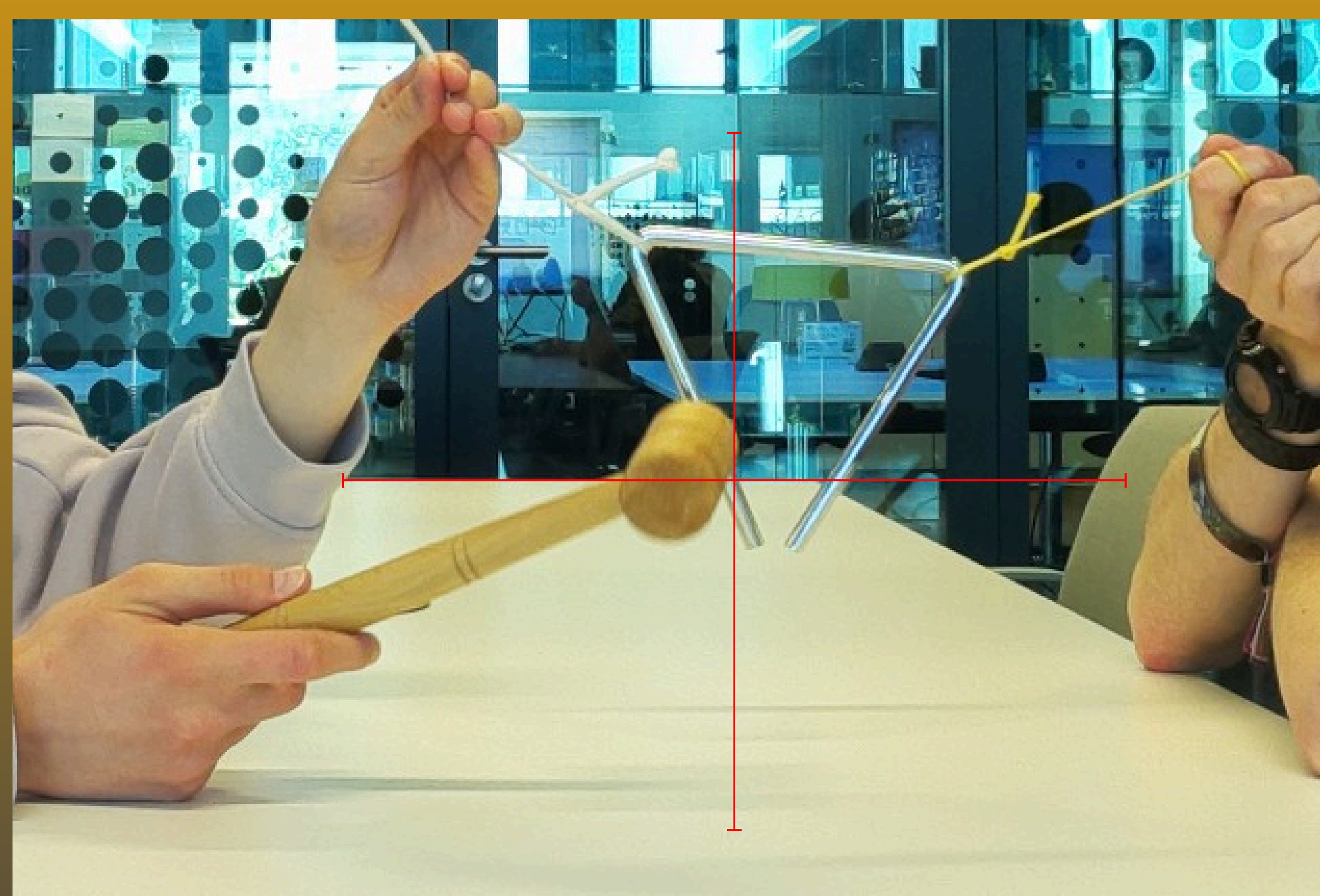


Figure 5: A cropped version of the result of our final measurement. The original 1920x1440 picture was cropped to for better visibility. The red cross is the found coordinate with its error-margin.

5. References

[1]. de Lucia, D. (2021). Implementation of a low-cost acoustic camera using arrays of MEMS microphones [Master's Thesis, POLITECNICO DI MILANO], https://www.politesi.polimi.it/retrieve/84d6b8b9-be88-4655-8f34-f15b6699fe08/2021_12_De%20Lucia.pdf

[2]. van der Marel, C. (2024). Group-24-DIYacousticcamera [Software]. GitHub. https://github.com/Camiel023/acousticcamera-group24

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