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THE USE OF MATHEMATICAL MODELS FOR THE CREATION OF LOW-COST MOSQUITO IDENTIFICATION DEVICES.

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Abstract. *Insects are closely linked to human life, both in a positive and negative sense. Although it is estimated that insects pollinate at least two-thirds of all food consumed by humans, on the other hand, there are malaria and dengue which are diseases transmitted by the female mosquitoes of the genus Anopheles (malaria) and Aedes aegypti (dengue). This problem kills hundreds of people a year. Because of the importance of insects to humans, researchers have developed an arsenal of mechanical, chemical, biological, and educational tools to help mitigate the harmful effects of insects. However, the efficiency of these tools depends on prior knowledge, as early as possible, of the time and location of migrations, infestations, and populations of the mosquito type. Insect detection and counting are typically performed using traps, which are regularly collected and manually analysed. The main issue is that this procedure is expensive in terms of both materials and human time and creates a delay between the time the trap is placed and the time the trap is inspected. This time lag may be as little as a week, but it is enough time for the development of a new mosquito's adult life. The goal is to use various mathematical models to try to identify the sounds of each types of mosquito species. Considering this, our study focused on the creation of a conceptual project for the identification of different mosquito species using a gadget developed with low-cost components. In this process, the mosquito signals are captured and the analogue signals processed for identification using a chosen mathematical method of classification implemented on a micro-controller.*

Thus, we make it possible to identify the species of each mosquito, allowing the monitoring of populations of these insects and the identification of the species responsible for the transmission of certain diseases.

Keywords: *Filters, mosquitoes, signal processing, Micro-controllers, Amplification*

1. INTRODUCTION

Mosquitoes are responsible for transmitting many infectious diseases, including malaria, dengue, and the Zika virus. Identification of the mosquito species responsible for transmitting a given disease is essential for the development of effective control measures. Traditional methods of mosquito identification, such as visual inspection of specimens, can be time-consuming and require specialist knowledge.

Recent advances in signal processing techniques have made it possible to identify mosquito species based on the sounds they make. Mosquitoes make characteristic sounds in flight, and these sounds can be recorded and analyzed using signal processing methods. By analyzing the frequency content of the sound produced by a mosquito, it is possible to identify the specific frequencies that are characteristic of each mosquito species.

Signal processing-based mosquito identification has several advantages over traditional methods. It is non-invasive, requires minimal specialist training, and can be performed quickly and easily using portable equipment. Furthermore, it can be used to identify mosquito species in real time, allowing immediate action to control mosquito populations. [Kiskin *et al.* (2017)]

Recently, the development of low-cost, portable acoustic monitoring devices has made mosquito identification based on signal processing even more accessible. These devices can be used to monitor mosquito populations in the field,

providing important information for disease control efforts.

Overall, signal processing techniques are becoming increasingly significant tools for mosquito species identification. The use of these techniques can facilitate the development of more effective control measures, reduce the spread of mosquito-borne diseases, and improve public health outcomes.

2. OBJECTIVE

Over the years, there have been many studies based on processing mosquito signals to identify what type of mosquito it is. In some cases, the studies focus on genus, and in other cases, they focus on species. Most of these studies employed the use of artificial intelligence in identifying the various types of mosquitoes, either by gender or species.

This study has the same objective as the other studies, which is to identify mosquito species through their sounds, but instead of using artificial intelligence, in this case mathematical operations used for signal processing will be used.

Devices used to run artificial intelligence algorithms (such as neural networks) are often expensive. So, mathematical methods were adopted so that the algorithm could be transferred to a low-power microcontroller, which in turn helped in the construction of a cheap device for classifying mosquitoes. [Kiskin (2020)]

3. METHODOLOGY

3.1 Signal Processing

AAs stated in the introduction, to identify the types of mosquito species, for this, the sounds of the various mosquitoes must be obtained and analyzed. AA database of three different species of mosquitoes was used; this database contains tens of thousands of *.wave* files of registered mosquitoes [Potamitis (2018)]. These species are **Aegypti**, **Albopictusi** and **Albopictusi**.

The mathematical approaches used to analyze the mosquito signals were the Fourier transform, *wavelet* - more specifically, the continuous wavelet transform (CWT) - and spectrogram analysis. The Figures 1, 2 and 3 below show the amplitude of the temporal verses of the first three audios of the three selected mosquito species.

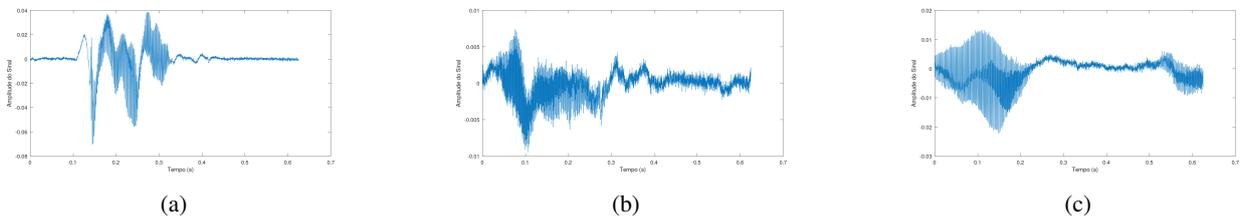


Figure 1: Os primeiros três sinais plotado no tempo dos áudios da especie Aegypti

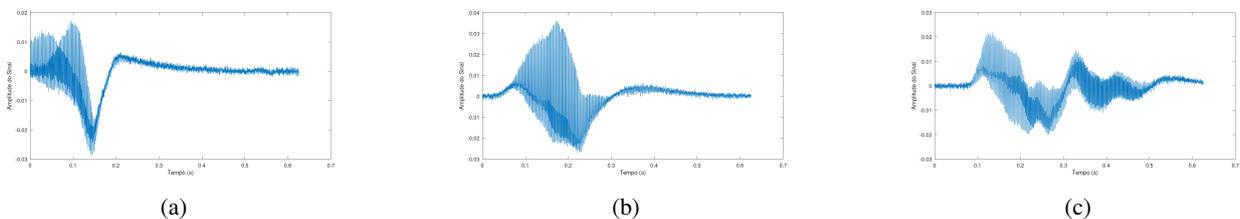


Figure 2: Os primeiros três sinais plotado no tempo dos áudios da especie Albopictusi

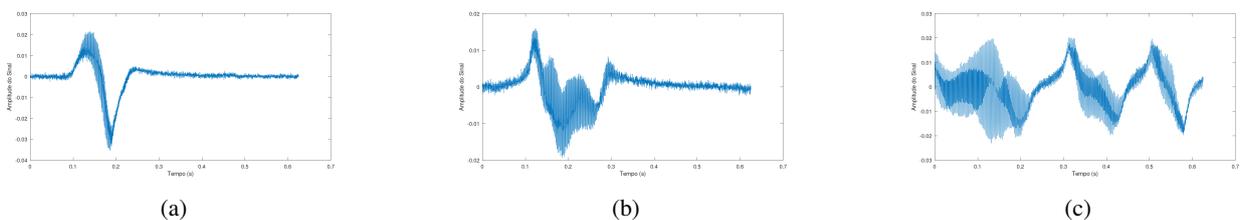


Figure 3: Os primeiros três sinais plotado no tempo dos áudios da especie Arabiensis

3.1.1 Fourier Transform Analysis

The Fourier transform is a mathematical technique that decomposes a time-domain signal into its constituent frequencies. In signal processing, the Fourier transform is used to analyze and manipulate signals in the frequency domain. The transform converts a time-domain signal into a frequency-domain representation, allowing you to identify the specific frequencies that make up the signal.

The Fourier transform can be expressed mathematically using an integral or a summation. The result of the transform is a complex function that describes the amplitude and phase of each frequency component in the signal. There are several variations of the Fourier transform, such as the discrete Fourier transform (DFT) and the fast Fourier transform (FFT), which are optimized to process discrete signals and can be efficiently calculated using algorithms. At this point in the study, the FFT method was chosen to analyze the frequencies present in each of the recorded audio files. As the audio signals used are digital signals (x) of length (N), converting them from the time domain to the frequency domain (X), the FFT formula used is presented in the equation 1 as:

$$X[h] = \sum_{i=0}^{N-1} (x[i]W_N^{ih}) \quad (1)$$

where $W_N = e^{-\frac{j2\pi}{N}}$ and $h = 0, 1, 2, \dots, N - 1$.

3.1.2 Wavelet Analysis

Wavelets are mathematical functions that can be used to analyze signals in the time and frequency domains, and are designed to capture the local and global characteristics of a signal. Unlike the Fourier transform, which provides information about the frequency content of a signal at all scales, *wavelets* can provide more detailed information about a signal at specific scales and locations.

wavelets can be used to analyze signals with complex characteristics that vary in scale, such as speech or music. They are also useful for analyzing non-stationary signals, which are signals that change over time and have varying frequency content.

The type of wavelet transform used is the continuous wavelet transform (CWT), which can provide different levels of detail and precision in the analysis, depending on the application and characteristics of the signal being analysed. Overall, wavelets provide a powerful tool for signal processing, allowing for more detailed analysis and feature extraction than traditional Fourier methods, which were used as the previous method. The continuous *wavelet* transform used can be expressed as;

$$C(a, b; f(t), \psi(t)) = \int_{-\infty}^{\infty} f(t) \frac{1}{a} \psi^* \left(\frac{t-b}{a} \right) dt \quad (2)$$

where for a scale parameter, $a > 0$, and position, b , and $(*)$ represents the complex conjugate.

3.1.3 Analysis with spectrograms

Spectrograms are a visual representation of the frequency spectra of a sound sample over a period of time. This analysis requires an examination of the energy distribution of sound at different frequencies over a specific interval, which may indicate changes in the content of the sound or the way it is being produced. This analysis fits perfectly in the sense of identifying acoustic signals when there is inconvenient noise.

The spectrograms can also be used to compare sound signals, identifying similarities and differences in the patterns of each sound. This can be done by generating the spectrograms of each signal and visually comparing them using specific software tools using techniques such as cross-correlation, dynamic time alignment (DTW) or feature extraction.

For our case, we integrate the spectrogram analysis with the Hash fingerprint technique, which creates a single and compact representation of the sound samples to compare and find matches, using the Hash algorithm. These algorithms create a unique and deterministic output, even if the input is slightly different. This technique identifies audio samples quickly and efficiently, as it is applied to small audio segments, generating a set of hashes, that are stored in a database to later be correlated with the next hashes. With this combination, we can increase accuracy, as it identifies audio snippets that have undergone some kind of processing, which may change the appearance of the audio in the temporal domain, but leave the appearance of the spectrogram relatively intact.

3.2 Hardware development

When creating this inexpensive device, many parameters need to be considered, for example, the price of components (they should not be expensive), but they must have the ability to perform the same or almost the same function. For these

reasons, the microphones used to capture these signals are a common electric microphone, an audio gain amplifier, and two Sallen Key filters, before the signal is processed by a microcontroller that contains the mathematical module used for identification. Of mosquito species. Figure 4 below shows the device's operating flowchart.



Figure 4: Device operation flowchart.

From the flowchart, it can be seen that the first stage is sound capture, followed by amplification, filtering, and, finally, the processing stage where the mosquito sounds will be identified.

3.2.1 Hardware Power Supply

One of the most important and basic things in every electronic device is the power input. In this case, the power input is a 5-volt, 3-amp direct current source. As all components run on 5V, these voltage sources will very well meet the power needs of the components to make them work well.

3.2.2 Capture

The initial phase of identifying the mosquito species in a neighbourhood boils down to the ability to capture the sound (the flapping of wings) of the mosquito. To make this possible, the Electret microphone was used.

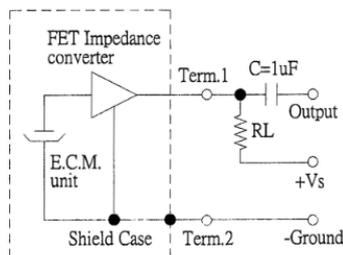


Figure 5: Microphone internal construction (Adapted from Datasheet (2022))

As can be seen in Figure 5, the Electret microphone uses electrostatic capacitor inside a capsule. It is widely used in recorders, telephones, mobile phones, as well as microphone-based headphones, Bluetooth headphones [Datasheet (2022)].



Figure 6: Electret Microphone Image

Figures 6 and 7 show the microphone image and the scheme of the sound capture phase respectively.

In the schematic in Figure 7, it can be seen that the negative terminal of the microphone is connected to ground, and the positive terminal goes straight to the amplifier so that the signal is amplified.

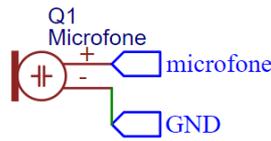


Figure 7: Schematic of the capturing part

3.2.3 Amplification

Amplification Audio signals cannot be connected directly from the capture step to the processing step, as the captured signals are so small that the ADC (Analogue to Digital Converter) of the microcontroller cannot interpret the signals. For this, there is a need for an amplification stage; the main function of this stage is to give a very significant gain to the input signal. In this case, the gain of the amplifier used is set to 200.

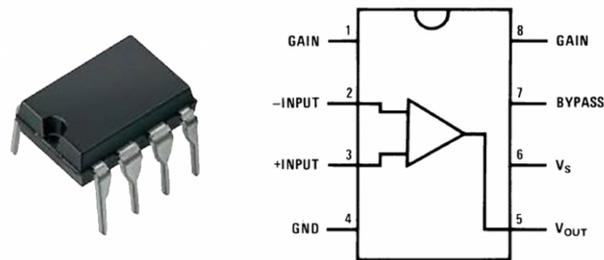


Figure 8: Image of the LM386 Amplifier and its pinout (Adapted from Instruments (2017))

The amplifier used in this amplification phase is the LM386 from *Texas Instruments*. This amplifier is mainly used as AM-FM radio amplifiers, portable cassette player amplifiers, intercoms, TV sound systems, line drivers, ultrasonic drivers, small servo drivers and energy converters [Instruments (2017)]. Looking at all these functions provided by datasheet [Instruments (2017)], it can be concluded that this component will serve very well for the amplification step.

Based on the schematic in Figure 9, the amplifier will provide 200 times the gain at the output, depending on the input. The $10\mu F$ capacitor between pins 1 and 8 (shown in Figure 8) is responsible for the 200 times gain of the amplifier.

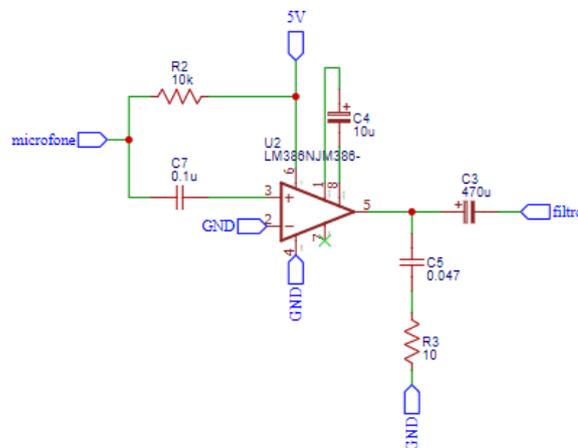


Figure 9: Amplification part schematic

As shown in the schematic of Figure 9, the amplifier receives the sound signal from the capture circuit and, based on its configuration, gives an amplified output. This output can be fed directly to a loudspeaker, but in this case, it will be fed to the third stage, which is a filter. The amplifier designed for this stage works with a voltage input of 5 volts for ground.

3.2.4 Filtering

Filters are electronic circuits that allow certain frequencies to pass through them and reject others. A filter can function as a high pass or a low pass; as the name implies, the high pass allows higher frequencies, greater than the cutoff frequency, to pass through it, while the low pass allows lower frequencies. Let the cutoff frequency pass through them.

Advanced filters like notch and bandpass can be obtained from these two basic filters. There are two main types of filters: passive and active. Passive filters are mainly made for passive components like resistors, capacitors, and inductors, and active filters mainly contain active components like op amps [Svoboda and Dorf (2013)].

The type of filter chosen for device development is an active filter. The active filter was selected because active filters have the following advantages over passive filters: gains can be greater than one, active filters can be cascaded without loading and impedance matching problems, and active filters can be built without the use of inductors, which are bulky. The essence of this phase is to remove any unwanted noise that might reside in another frequency spectrum that we are not interested in, and allow only the frequencies we are interested in (the frequency band where mosquitoes' wing beats are known). For this, a Sallen-Key bandpass filter is used, and as it is an active filter, it means that an operational amplifier will be used. So, the MAX4475 was chosen.



Figure 10: Image of MAX4475 (Adapted from Products] (2002))

The MAX4475 is a high-bandwidth, low-noise, low-distortion op-amp that is used in ADC buffers, DAC (Digital-toAnalogue converter) output amplifiers, low-noise microphone pre-amplifiers, digital scales, meters, voltage sensors, sensor amplifiers, and medical equipment.

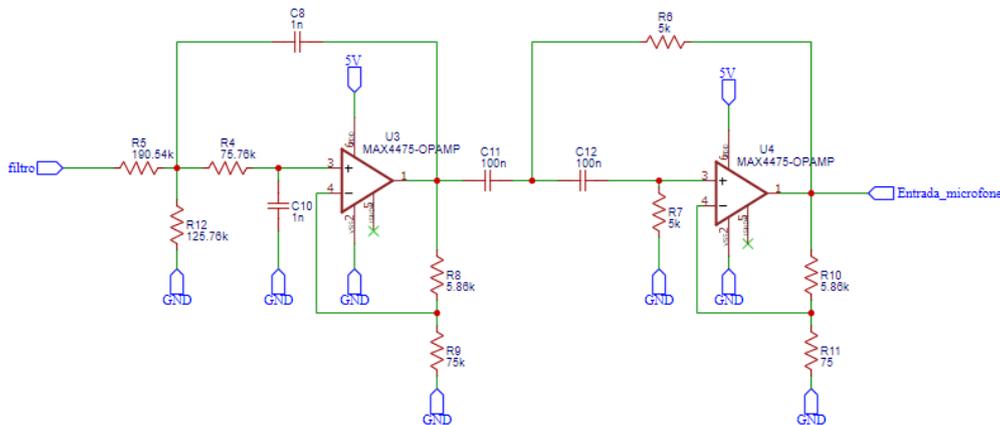


Figure 11: Schematic of Sallen-Key filter

Figure 11 shows the scheme of the bandpass filter Sallen-Key designed for this device. The first stage of the filter is a low pass filter with a cutoff frequency of 2.1KHz and the second stage is a high pass filter with a cutoff frequency of 350Hz. The Equation 3.

$$f = \frac{1}{2\pi fc} \tag{3}$$

This means that the filter only allows audio signals within the 350Hz and 2.1KHz frequencies. According to the research done for the mosquito identification algorithm, the wing beats of the mosquitoes are within this range, so with the filter, we can focus more on the analysis within this range instead of focusing on the entire frequency spectrum that enters the microphone. . Even though it is a second-order filter, it is designed to have a gain of 1.

3.2.5 Signal Processing

This is the most important part of the device because it works like the brain. The component used is ATMEGA328p from *ATMEL Corporation*. ATMEGA328p is a high-performance, low-power 8-bit AVR microcontroller chip and its architecture is based on the advanced RISC (*Reduced Instruction Set Computer*) [Cooperation (2011)] architecture. *figure 12* shows an image of the ATMEGA328P chip.

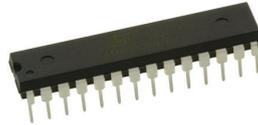


Figure 12: Image from ATMEGA328p. (Adapted from Cooperation (2011))

It is seen that the micro-controller has a lot of GPIO (*General Purpose Input/Output*) which is also used to control some of the peripherals, but in this case only a few will be used. As shown in the *figure 13* scheme, for the component to work it is necessary to connect it to the 5V power supply with two coupling capacitors to remove all noise from the power supply. A 16MHz crystal is connected to the micro-controller to execute the instructions. There is also a reset button connected, as the name implies, it does a reset on all micro-controller activities (including instructions) every time the button is pressed.

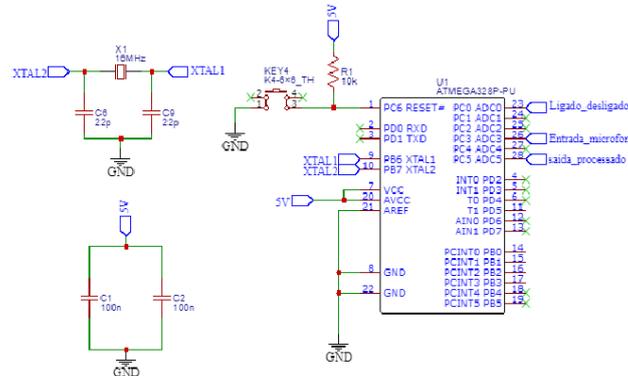


Figure 13: Schematic of the Signal Processing phase

It is seen that the micro-controller has a lot of GPIO (*General Purpose Input/Output*) which is also used to control some of the peripherals, but in this case only a few will be used. As shown in the *figure 13* scheme, for the component to work it is necessary to connect it to the 5V power supply with two coupling capacitors to remove all noise from the power supply. A 16MHz crystal is connected to the micro-controller to execute the instructions. There is also a reset button connected, as the name implies, it does a reset on all micro-controller activities (including instructions) every time the button is pressed.

For this component to perform its function, it needs to be programmed. This program is based on the most effective and efficient algorithm (based on the mathematical method used for mosquito species identification) chosen. This algorithm aims to identify the mosquito species based on the sound it makes with its wings. This sound signal enters the micro-controller after the filtering stage through the ADC, where the analogue signal is converted into a digital signal based on the 8-bit resolution of the ADC. The digital signal is then processed by the algorithm and the output is then produced.

4. Results

4.1 Signal Processing

All audio for the three different species was analysed with the three different models of mathematical frequency aliasing. In this section, species frequencies were analysed to show which model performed best and can be used in the proposed low-cost mosquito identification equipment.

4.1.1 Fourier Transform Analysis

Figure 14 showcases the outcomes of Fast Fourier Transform (FFT) applied to *Aedes aegypti* audio signals and Figures 15 and 16 showcases the outcomes of FFT applied to *Albopictus* and *Arabiensis* respectively. The resulting plots provide

visualization of the distinct frequency components present in the audios.

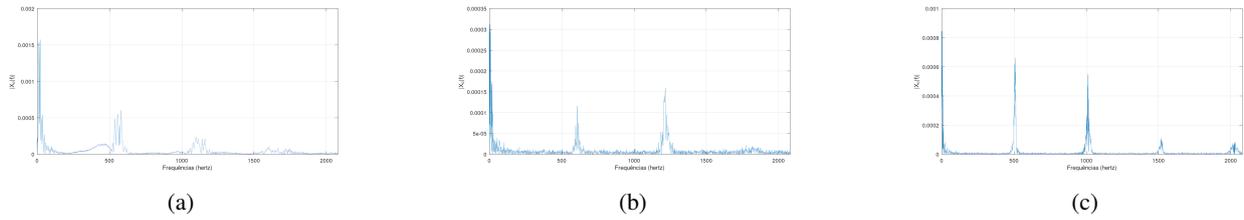


Figure 14: Plotting the signals after applying FFT to the Aegypti audios

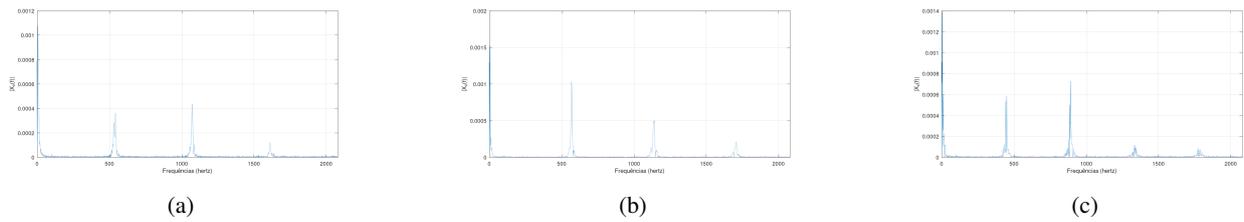


Figure 15: Plotting the signals after applying FFT to the Aegypti audios

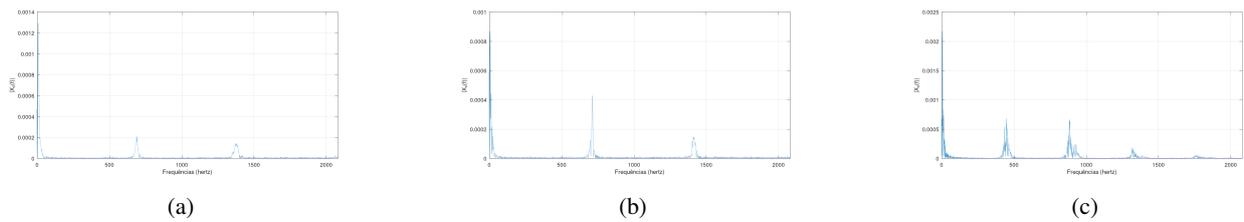


Figure 16: Plotting the signals after applying FFT to the Arabiensis audios

4.1.2 Wavelet transform Analysis

wavelets analysis was done using *PyWavelets* is an open source wavelet transformation software for PYTHON. By applying CWT, a scalogram can be constructed from the signal. where a parameter is added to allow cutting longer waves (lower frequencies). Figure 17 unveils the results of applying these wavelets to *Aedes aegypti* audio signals and Figures 18 and 19 showcases the outcomes of wavelet transformation applied to *Albopictus* and *Arabiensis* respectively.

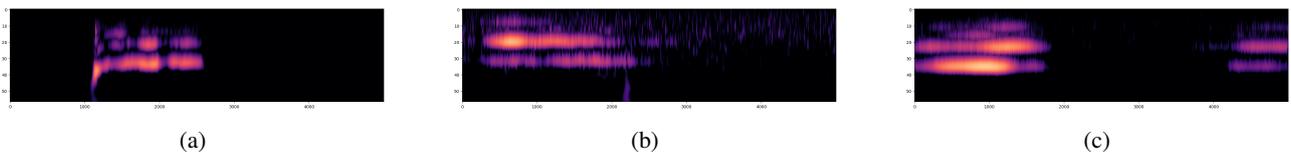


Figure 17: Image of audio samples after wavelet analysis on Aegypti signals

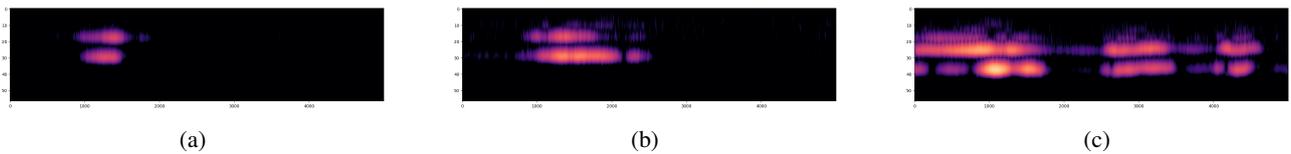
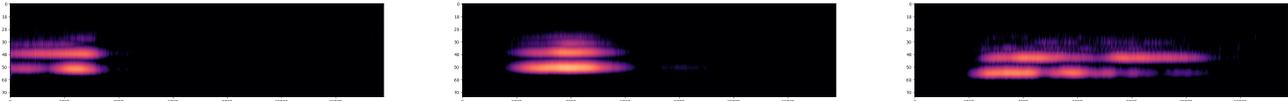


Figure 18: Spectrogram image after wavelet analysis on Arabiensis signals

The tables below presents numerical values assessing the similarity between the species through the analysis of wavelet outputs. The data presented in the Table 1 aims to provide a quantitative basis between *Aedes Aegypti* and the other 2 species. Table 2 and Table 3 provide the same quantitative basis between *Albopictus* and *Arabiensis* respectively with the other species for understanding the relationships and distinctions in the wavelet patterns.



(a) (b) (c)
Figure 19: Image of audio samples after wavelet analysis on Albopictus signals.

Table 1: Numerical values comparing the similarity between other species and Aegypti using wavelet outputs.

Espécie	Aegypti			
	Amostras de áudio	Amostra 1	Amostra 2	Amostra 3
Aegypti	Amostra 1	0	15,6369	19,0926
	Amostra 2	15,6369	0	42,4518
	Amostra 3	19,0926	42,4518	0
Albopictus	Amostra 1	40,5581	70,0582	63,6911
	Amostra 2	35,5894	66,0477	61,3286
	Amostra 3	34,665	62,2864	62,7408
Arabiensis	Amostra 1	22,6164	60,6743	51,5158
	Amostra 2	15,4603	49,4411	47,256
	Amostra 3	17,4078	43,8579	29,3415

Table 2: Numerical values comparing the similarity between other species and Albopictus using wavelet outputs.

Espécie	Albopictus			
	Amostras de áudio	Amostra 1	Amostra 2	Amostra 3
Aegypti	Amostra 1	40,5581	35,5894	34,665
	Amostra 2	70,0582	66,0477	62,2864
	Amostra 3	63,6911	61,3286	62,7408
Albopictus	Amostra 1	0	39,21	36,7707
	Amostra 2	39,21	0	24,6178
	Amostra 3	36,7707	24,6178	0
Arabiensis	Amostra 1	53,1396	47,9098	76,6443
	Amostra 2	52,8169	47,1365	74,9924
	Amostra 3	50,3954	47,0537	73,7738

Table 3: Numerical values comparing the similarity between other species and Arabiennis using wavelet outputs.

Espécie	Arabiennis			
	Amostras de áudio	Amostra 1	Amostra 2	Amostra 3
Aegypti	Amostra 1	22,6164	15,4603	17,4078
	Amostra 2	60,6743	49,4411	43,8579
	Amostra 3	51,5158	47,256	29,3415
Albopictus	Amostra 1	53,1396	52,8169	50,3954
	Amostra 2	47,9098	47,1365	47,0537
	Amostra 3	76,6443	74,9924	73,7738
Arabiennis	Amostra 1	0	0,3903	4,8883
	Amostra 2	0,3903	0	18,9619
	Amostra 3	4,8883	18,9619	0

4.1.3 Spectrogram Analysis

As can be observed in Tables 1, 2 and 3, the MSE (Mean Squared Error) method was applied to the audio results after being processed by the spectrogram. These results were able to provide consistent numerical values to demonstrate that the method was capable of distinguishing between species, as shown in Tables 4, 5, and 6, where the wavelet technique is presented.

The images 20 and 21 illustrates the application of Spectrogram Analysis on Aedes aegypti and Arabiennis audio recordings respectively.

The tables 4, 5 and 6 below presents similar numerical values of the Tables 1, 2 and 3 but assessing the similarity

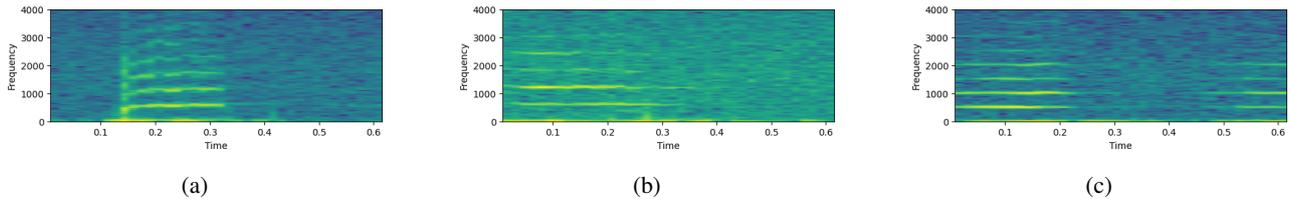


Figure 20: Image of audio samples after spectrogram analysis on aegypti signals.

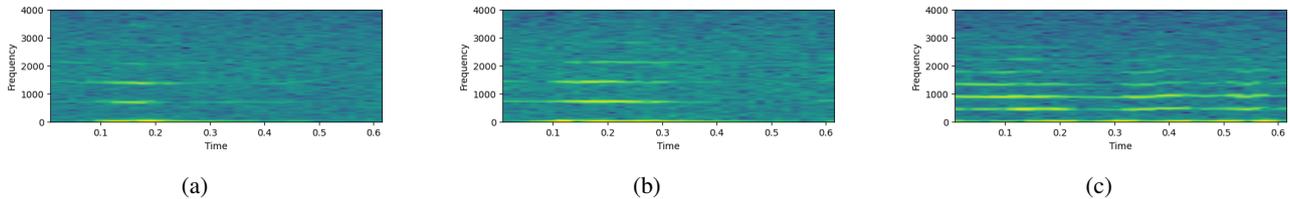


Figure 21: Image of audio samples after spectrogram analysis on Arabiensis signals.

between the species through the analysis of wavelet with the mean squared error method (MSE) outputs. The data presented in the Table 4 aims to provide a quantitative basis between *Aedes Aegypti* and the other 2 species. Table 5 and Table 6 provide the same quantitative basis between *Albopictus* and *Arabiensis* respectively with the other species for understanding the relationships and distinctions in the MSE patterns.

Table 4: Properties obtained after processing between other species and *Aegypti*

Espécie	Aegypti			
	Amostras de áudio	Amostra 1	Amostra 2	Amostra 3
Aegypti	Amostra 1	0	7,4686	34,2052
	Amostra 2	7,4686	0	7,8168
	Amostra 3	34,2052	7,8168	0
Albopictus	Amostra 1	25,8623	101,701	21,7255
	Amostra 2	17,2431	84,1866	16,7368
	Amostra 3	16,6266	76,1266	14,5121
Arabiensis	Amostra 1	18,9422	85,28	16,0472
	Amostra 2	15,0853	71,4512	13,5259
	Amostra 3	23,0463	89,8283	18,6362

Table 5: Properties obtained after processing between other species and *Albopictus*

Espécie	Albopictus			
	Amostras de áudio	Amostra 1	Amostra 2	Amostra 3
Aegypti	Amostra 1	25,8623	17,2431	16,6266
	Amostra 2	101,701	84,1866	76,1266
	Amostra 3	21,7255	16,7368	14,5121
Albopictus	Amostra 1	0	33,9385	42,7893
	Amostra 2	33,9385	0	32,3298
	Amostra 3	42,7893	32,3298	0
Arabiensis	Amostra 1	13,9266	23,5068	30,4569
	Amostra 2	11,0149	19,2165	25,6312
	Amostra 3	19,0345	29,8869	32,4412

4.2 Hardware development

According to the methodology, the project was divided into four phases: capturing, amplifying, filtering, and processing. The project was simulated, and the simulated circuit gave positive results. The ATMEGA328p standalone circuit also worked perfectly after being simulated along with the voltage source circuit.

From the Figure 22 shown below, an AC frequency sweep simulation was made to check if the band pass filter Sallen-Key will be able to reject all frequencies not needed. And that too proved to be a success.

Table 6: Properties obtained after processing between other species and Arabiensis

Espécie	Arabiensis			
	Amostras de áudio	Amostra 1	Amostra 2	Amostra 3
Aegypti	Amostra 1	18,9422	15,0853	23,0463
	Amostra 2	85,28	71,4512	89,8283
	Amostra 3	16,0472	13,5259	18,6362
Albopictus	Amostra 1	13,9266	11,0149	19,0345
	Amostra 2	23,5068	19,2165	29,8869
	Amostra 3	30,4569	25,6312	32,4412
Arabiensis	Amostra 1	0	11,2863	25,5383
	Amostra 2	11,2863	0	36,4546
	Amostra 3	25,5383	36,4546	0

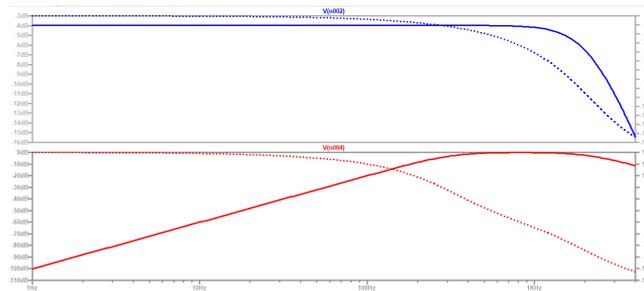


Figure 22: Frequency responds of the band-pass Sallen-Key filter.

A simulation of the amplification step was performed, which can be seen in Figure 23. In Figure 23 it can be seen that the amplification has a gain of 200V/V, as previously stated, because the amplification circuit shown in Figure 9 has a gain of 200V/V.

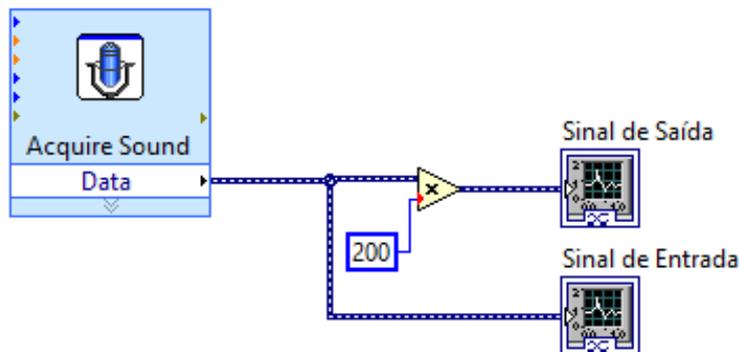


Figure 23: Image to show how the amplifier was simulated

The audio signal was captured using a microphone during the simulation. This audio signal is then amplified with the gain that the amplifier provides. From Figure 24, a graph of input signal amplitude as a function of time is shown. By Figure 24, the maximum amplitude is around 0.12V.

After the signal has been amplified, the output of is plotted the same way the input was plotted. In Figure 25, the maximum output voltage is around 24V. But this will not be the case for mosquito signals as they have a very low amplitude.

4.3 Conclusion

The Fourier method was not very useful for our application because it displayed all the frequencies present in the audio in a graph without the ability to analyze them over time. Since time analysis is crucial in this project, this method fell behind compared to others.

When analyzing wavelet tables, it was observed that the behavior profiles of the samples were different for each mathematical model. Methods such as Peak Signal-to-Noise Ratio (PSNR), Cross Entropy Difference (CEDD), and

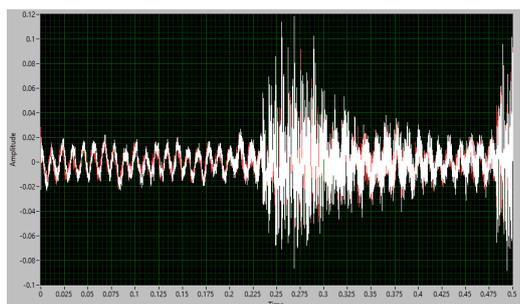


Figure 24: Graph to show the amplitude of the signal.

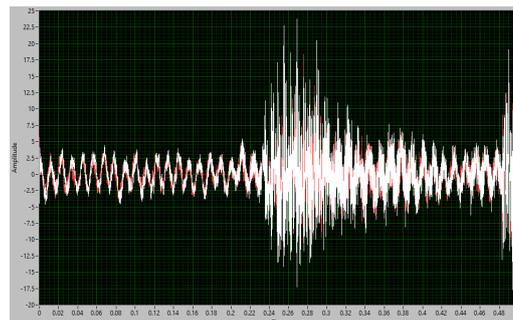


Figure 25: Graph to show the amplitude of the amplified signal

Structural Similarity Index (SSIM) were also tested. It is important to note that the choice of method depends on the analysis objective, data characteristics, and specific parameter selection, such as the signal size for each method.

In our case, satisfactory results were obtained only for the wavelet with the Mean Squared Error (MSE) method. This is because wavelets contain significant structural information that is often used for image and audio signal processing.

For spectrograms, the application of these same methods did not yield good results. This is because spectrograms represent the time and frequency domains of a signal and do not possess the same structure as wavelets. Specific methods that consider the spectral nature of the data may be more suitable for this type of signal.

In conclusion, after analyzing and comparing the Fourier, spectrogram, and wavelet methods, it can be stated that for our application of identifying the species of mosquitoes from the received sound signal, the wavelet transform was more suitable due to its ability to provide valuable information in both the time and frequency domains, as well as the energy distribution across different frequency scales. Our results also demonstrated that this transform is an effective method for processing sound signals.

It was observed that while the Fourier method is useful for frequency analysis, it is unable to provide detailed information about the temporal evolution of the signal. The spectrogram, on the other hand, allows visualization of the temporal evolution and spectral energy distribution of the signal but may not be suitable for more detailed and precise analyses.

Based on the conceptual design carried out and the simulation results, it can be confirmed that the device will be functional when built. Considering that all phases of the flowchart are theoretically sound and functional, it is recommended that it be constructed.

The device has the potential to especially help people in areas where mosquito populations are high and cause a lot of health problems when developed. This project can be improved with additional research on electronic components used in the main stages, such as the microphone, the amplifier, and the microcontroller used for signal processing and mosquito identification.

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