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Original Article

Quality Comparison of Upcycled Guitars and Standard Guitars using Fourier Transforms and Phyphox Tools

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Abstract *- Guitars have been a significant and expensive musical instrument that is not accessible to many people in our society. A comparison of the tone produced by different guitars made of different materials has been conducted. The tone produced by the guitar depends on many factors, such as the material used, string gauge, string type, etc. The influence of the material used to create the body and other parts is crucial in an acoustic guitar. Changing the body material or shape or even the design of a guitar may influence its tone in various ways. Two guitars have been created using recycled material and compared with a standard guitar. Phyphox has been used in this research study to record and compare the tone produced by low-cost, upcycled musical instruments made of recycled material and a standard acoustic guitar - Yamaha F280. Fourier transforms have been used to convert the recorded waves from the time domain to the frequency domain.*

Keywords *- Acoustic guitar, Fourier transforms, Phyphox, Recycled and upcycled, Time domain and frequency domain, Tone.*

1. Introduction

Guitars have been one of the most used and unique musical instruments since the early 16th century [1]. The body of the early guitar was narrower, more profound and had 4 strings only. The modern acoustic guitar is made using a variety of woods like mahogany, ash, and maple, and it comprises six nylon or steel strings. The tone and the quality of sound produced depend on numerous factors such as the material used, gauge of string used, type of string used, etc. In simple terms, the tone is a sound wave with a single frequency [2]. A good quality musical instrument will produce a sound wave with a consistent pattern. Sound signals can be studied in frequency and time domains. In ideal situations, a pure tone in the frequency domain would look like one single peak and like a cosine or sine curve in the time domain. Fourier transforms, and the Fourier series converts a function's time-domain representation to its frequency-domain and vice versa [3]. An example of the Fourier Transform is shown in Fig.1.

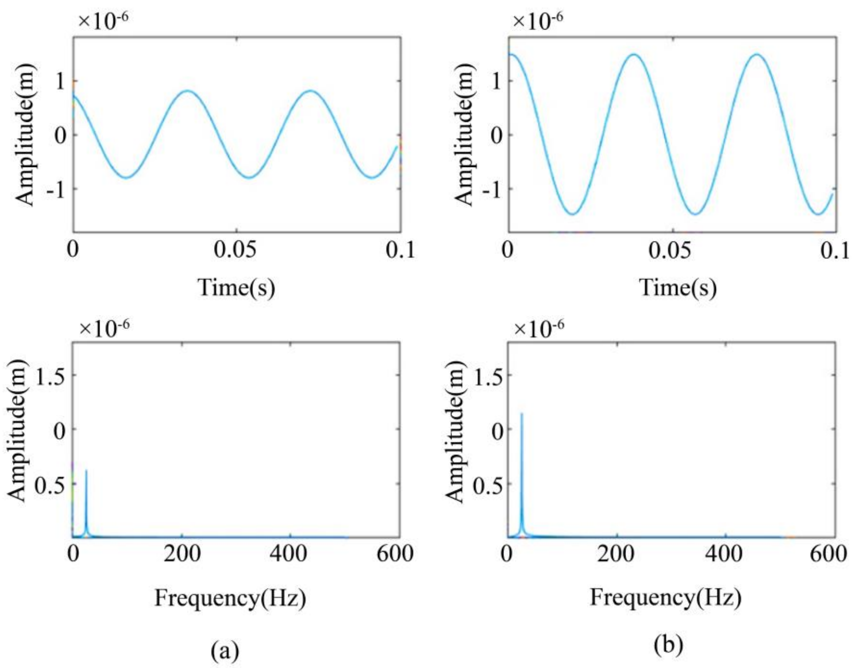

Fig. 1 An example of fourier transform [5]

One of the research papers that looks into the quality of guitar tone is "Measuring The Quality of Guitar Tone" [6] by Samo Sali and Janez Kopac. In this paper, they have tried to determine the most crucial feature of the tone of a good guitar and how it can be differentiated from a bad guitar using consonance and dissonance using Fast Fourier transformation. In this research paper, two guitars are made using recycled waste material. According to the World Bank, the global extreme poverty rate reached 9.3%, up from 8.4% in 2019 [7] (extreme poverty is defined as those who live on less than $2.15 per person per day). Children born in middle-class households and other people from similar access have all the access in the world to music and musical instruments. However, children from poor households are the ones who are excluded from many of these opportunities [8]. Because of this, many young children who may be very talented and interested in music are deprived of musical instruments. A study at Northwestern University also shows that music lessons can help alleviate poverty's psychological damages - including increased self-esteem and a general motivation in life [10]. Moreover, these instruments promote sustainability and ultimately end up reducing the exploitation of natural resources that are at risk of extinction during the production of the instruments[11]. By the end of this paper, we will be able to have a better idea about the quality difference between the tone produced by the low-cost, homemade acoustic guitars made out of day-to-day available items and that of a standard guitar. The research paper compares the tones produced by guitars made out of waste with a standard guitar.

2. Methodology

2.1. Aim of the Study

The aim of this study is to compare the tone produced from two guitars made from recycled materials with a standard guitar and assess the difference in the quality of tone produced from these guitars. In this study, various factors were compared, and the sound from the guitars was recorded using Phyphox[12] on a smartphone and analysed using Python[13] interpreter software, Pycharm [15].

2.2. Research Design

This is an experimental type of research study.

2.3. Production of the Guitars

The upcycled acoustic guitar has been made using speaker boxes, a broken old guitar (neck and bridge), and steel strings. The neck is removed from an old, broken acoustic guitar and attached to the wooden speaker box using nails which are hammered in firmly. The bridge is also attached using screws and super glue. Fig. 2 is the image of the produced guitars.

2.4. Conditions of Experiment

All recordings have been conducted in the same ordinary room at around midnight with little to no background noise to simulate ideal conditions. The index finger has been used to excite the strings, and I have tried to keep the force of striking the string constant.

2.5. Hypothesis

2.5.1. Null Hypothesis

The quality of the tone produced by the guitars made from upcycled material is comparable to the quality of the tone produced by the standard acoustic guitar.

2.5.2. Alternate Hypothesis

The quality of the tone produced by the guitars made from upcycled material differs from the quality of the tone produced by the standard acoustic guitar.

(a)

(b)

(c)

(d) **(e)**

(f)

Fig. 2 a) Guitar 1 Top View, b) Guitar 1 Side View, c) Guitar 1 Diagonal View, d) Guitar 2 Top View, e) Guitar 2 Side View, f) Guitar 2 Diagonal View

2.6. Data Collection Procedure

The guitar was about 15 cm away from the recording phone on a table, and the string was excited using the index finger. The fourth string, or string 'D', has been excited in each case. Four features of Phyphox have been used:

1. Audio Amplitude: Audio amplitude has been used to measure the recorded signal's sound pressure level (Volume).
2. Audio Autocorrelation: Audio autocorrelation is used to find the frequency and period of the single note we intend to analyse.
3. Audio Spectrum: Audio spectrum uses Fourier transformation to convert the signal from the time domain to the frequency domain.
4. Audio Scope: Audio scope is used to study wave nature.

All data recorded using Phyphox was exported as CSV(Comma, decimal point) files.

3. Results and Discussion

All codes have been written and plotted using the Python interpreter software Pycharm.

Code 1: Used to plot Amplitude vs Time

```
# importing modules
from pandas import *
import matplotlib.pyplot as plt

# reading data
data1 = read_csv("Amplitudes_guitar_1.csv") data2
= read_csv("Amplitudes_guitar_2.csv")
data3 = read_csv("Amplitudes_standard_guitar.csv")
# reading columns
time1 = data1['Time (s)'].tolist()
time2 = data2['Time (s)'].tolist()
time3 = data3['Time (s)'].tolist()
amp1 = data1['Sound pressure level (dB)'].tolist()
amp2 = data2['Sound pressure level (dB)'].tolist()
amp3 = data3['Sound pressure level (dB)'].tolist()

# plotting
plt.plot(time1,amp1, c="red", label="Guitar_1")
plt.plot(time2,amp2, c="blue", label="Guitar_2")
plt.plot(time3, amp3, c="black", label="Standard_Guitar")
plt.scatter(time1,amp1, s=5) plt.scatter(time2,amp2, s=5)
plt.scatter(time3,amp3, s=5)
plt.xlabel("Time (s)")
plt.ylabel("Sound Pressure Level (dB)")
plt.title("Amplitude vs Time")
plt.legend(["Guitar_1", "Guitar_2", "Standard_Guitar"])
plt.show()
```

Code 1 has been used to plot all the data from the three CSV files "Amplitudes_guitar_1", "Amplitudes_guitar_2", "Amplitudes_standard_guitar" which are recorded using the Audio Amplitude feature in Phyphox.

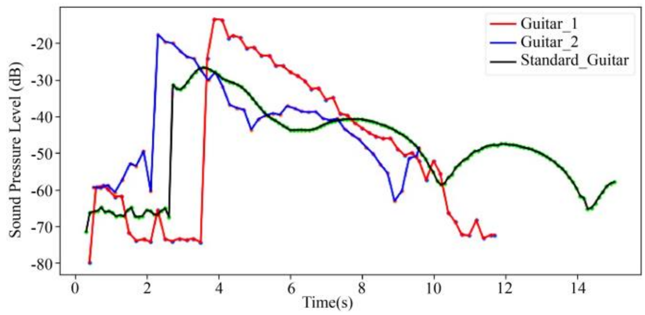

Fig. 3 Amplitude vs Time graph comparing all guitars

Fig. 3 is the graph that has been obtained after running Code 1. This graph compares all three guitars' sound pressure levels (dB) vs time. Fig 3. clearly shows that the graphs of Guitar 1 and Guitar 2 stop at around 12 seconds and 10 seconds, respectively. In contrast, the graph of the standard guitar goes up to 29 seconds (the image only shows 16 seconds, but it has been cropped so that the data of Guitar 1 and Guitar 2 can be analysed properly). This implies that Guitar 1 and Guitar 2 have a similar sustain, but the Standard Guitar has a substantially longer sustain than the other guitars. Sustain is simply a term used to describe how long the guitar strings vibrate. Sustain is directly proportional to the tone quality produced by a musical instrument [16]. This means that the longer the sustain, the better the tone quality produced.

Code 2: Used to plot Autocorrelation (a.u.) vs Delay (ms)

```
# importing modules
from pandas import *
import matplotlib.pyplot as plt

# reading data
data1 = read_csv("Autocorrelation_guitar1.csv") data2
= read_csv("Autocorrelation_guitar2.csv")
data3 = read_csv("Autocorrelation_standardguitar.csv")


# reading columns
delay1 = data1['Delay (ms)'].tolist()
delay2 = data2['Delay (ms)'].tolist()
delay3 = data3['Delay (ms)'].tolist()
au1 = data1['Autocorrelation (a.u.)'].tolist()
au2 = data2['Autocorrelation (a.u.)'].tolist()
au3 = data3['Autocorrelation (a.u.)'].tolist()

# plotting
plt.subplot(3, 1, 1)
plt.plot(delay1, au1)
plt.scatter(delay1, au1, s=5)
plt.xlabel("Delay (ms)")
plt.ylabel("Autocorrelation (a.u.)")
plt.title("Audio Autocorrelation- Autocorrelation (a.u.) vs
Delay (ms)")
plt.legend(["Guitar 1"])
plt.grid(color='grey', linestyle='-', linewidth=0.75)
plt.subplot(3, 1, 2)
plt.plot(delay2, au2)
plt.scatter(delay2, au2, s=5)
plt.xlabel("Delay (ms)")
plt.ylabel("Autocorrelation (a.u.)")
plt.legend(["Guitar 2"])
plt.grid(color='grey', linestyle='-', linewidth=0.75)
plt.subplot(3, 1, 3)
plt.plot(delay3, au3)
plt.scatter(delay3, au3, s=5)
plt.xlabel("Delay (ms)")
plt.ylabel("Autocorrelation (a.u.)")
plt.legend(["Standard Guitar"])
plt.grid(color='grey', linestyle='-', linewidth=0.75)
plt.show()
```

Code 2 has been used to plot all the data from the three CSV files "Autocorrelation_guitar1", "Autocorrelation_guitar2", "Autocorrelation_standardguitar" so that it can be analysed properly.

Fig 4 is the graph that has been obtained after running Code 2. Autocorrelation is a mathematical representation of the degree of similarity between a given time series and a lagged version of itself over successive time intervals[17]. The main function of the "Audio Autocorrelation" feature in Phyphox is to calculate the period and ultimately find the frequency of the sound wave using the relation, $f = 1/T$…(1), where 'f' is the frequency and 'T' is the time period of the sound wave.

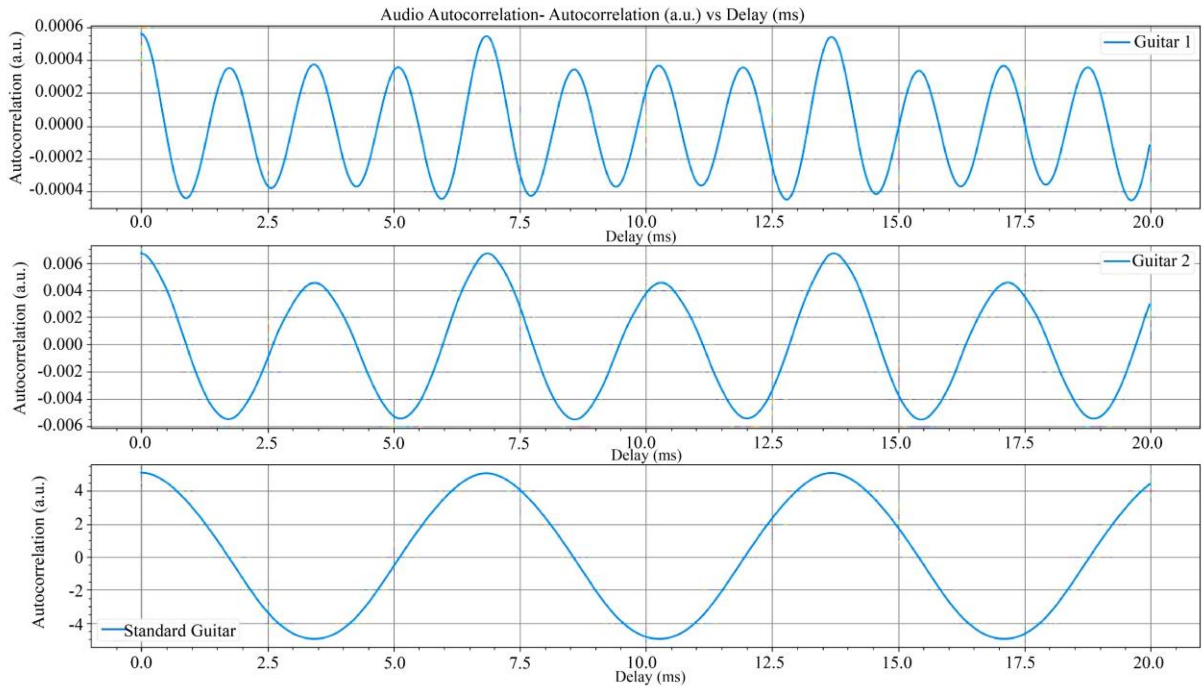

Fig. 4 Audio autocorrelation comparing all guitars

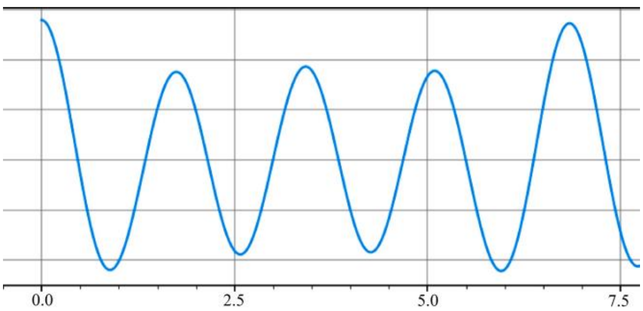

Fig. 5 Zoom in on the graph of Guitar 1 showing one full period

As we can clearly observe from Fig 5, one period is approximately 6.9ms. Using the relation in Eq. 1, the corresponding frequency comes out to be 144.93Hz. The periods from the graph of guitar 2 and guitar 3 can be observed similarly to Fig. 5. Both Periods can be approximately 6.8 ms. Therefore, using the relation in Eq. 1, the corresponding frequencies are approximately 147.06Hz. From this information, we notice that both Guitar 1 and Guitar 2 have frequencies similar to those recorded using the standard guitar when the 'D' string is excited. This implies that the tone produced by both Guitar 1 and Guitar 2 is very similar in quality to the tone produced by the standard guitar.

Code 3: Used to plot Recording (a.u.) vs time (s)

```
# importing modules
from pandas import *
import matplotlib.pyplot as plt

# reading data
data1 = read_csv("Raw_data_guitar1.csv") data2
= read_csv("Raw_data_guitar2.csv")
data3 = read_csv("Raw_data_standardguitar.csv")

# reading columns
time1 = data1['Time (s)'].tolist()
time2 = data2['Time (s)'].tolist()
time3 = data3['Time (s)'].tolist()
au1 = data1['Recording (a.u.)'].tolist()
au2 = data2['Recording (a.u.)'].tolist()
au3 = data3['Recording (a.u.)'].tolist()
plt.subplot(3, 1, 3)
plt.plot(time3, au3)
plt.scatter(time3, au3, s=5)
plt.xlabel("Time (s)")
plt.ylabel("Recording (a.u.)")
plt.legend(["Standard Guitar"])
plt.show()
```

This code has been used to plot all the data from the three CSV files "Raw_data_guitar1", "Raw_data_guitar2", "Raw_data_standardguitar" so that it can be analysed properly.

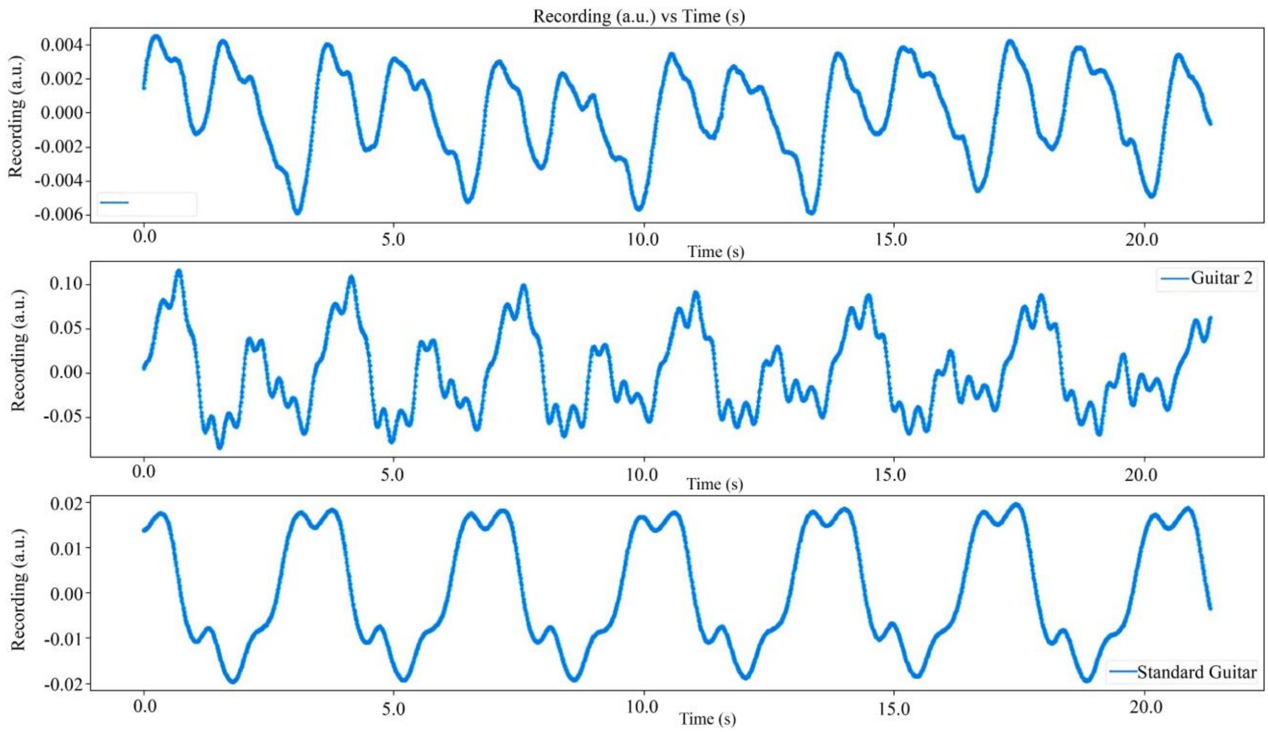

Fig. 6 Audio Spectrum - Before Fourier Transform

As we can observe in Fig. 6, the nature of the graph or the pattern of waves obtained from all three guitars is very similar. Since the graph of Guitar 2 follows an extremely similar pattern as compared to the graph of the standard guitar, we can infer that they are similar in quality. However, Guitar 1 has a slightly different-shaped graph. We can observe that the dips are not as defined, and even the peaks have slightly different shapes. This implies that the tone of Guitar 1 is slightly worse than the Standard Guitar.

Fourier transforms [18] have been used to convert the graphs in Fig. 6, which are in the time domain, to their frequency domain, as shown in Fig. 8 below. Phyphox has used Eq. 2 and Eq. 3 as shown below, for Fourier Transform.

$$f(t) = \int_{-\infty}^{\infty} F(\nu) e^{2\pi i \nu t}\, d\nu \ldots(2)$$

$$F(\nu) = \int_{-\infty}^{\infty} f(t) e^{-2\pi i \nu t}\, dt \ldots(3)$$

```
# plotting
plt.subplot(3, 1, 1) plt.plot(time1, au1)
plt.scatter(time1, au1, s=5) plt.xlabel("Time (s)")
plt.ylabel("Recording (a.u.)") plt.title("Recording (a.u.) vs
Time (s)") plt.legend(["Guitar 1"])
plt.subplot(3, 1, 2) plt.plot(time2, au2)
plt.scatter(time2, au2, s=5) plt.xlabel("Time (s)")
plt.ylabel("Recording (a.u.)")
plt.legend(["Guitar 2"])
```

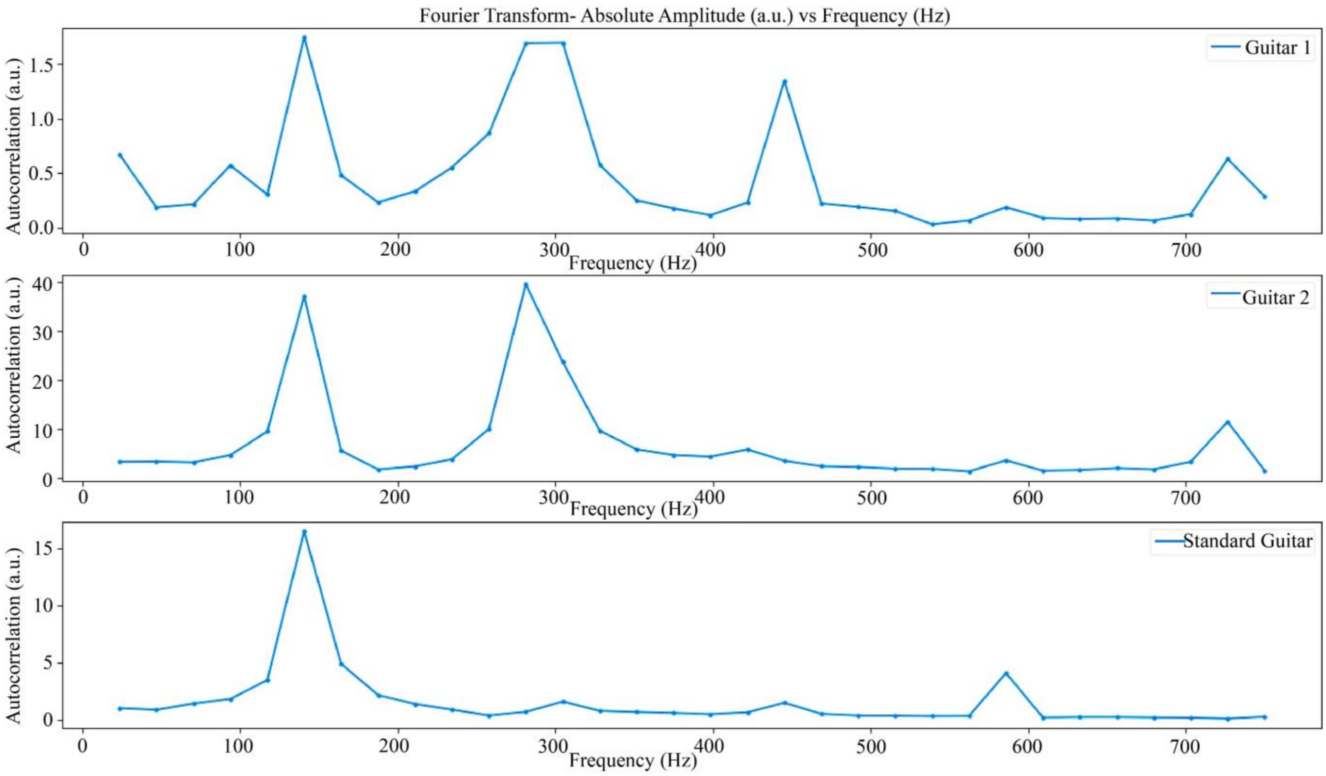

Fig. 8 Audio spectrum - After fourier transform

After the Fourier Transform, we get a plot of Absolute Amplitude (a.u) vs Frequency(Hz), which is the signal's Frequency Domain. This helps us see all the frequencies present in the sound waves in Fig. 6. In Fig. 8; it can be observed that the highest peak of the graphs of Guitar 1 and the Standard Guitar match exactly at around 145 Hz when the 'D' string is excited. This means that these guitars are similar in quality. However, in the graph for Guitar 2, we notice one peak higher than the peak at 145 Hz. There can be multiple explanations, including outside interference, a lower-quality guitar, or energy dissipation into the table. The multiple peaks present in the graph of Guitar 1 can be attributed to the same reasons.

4. Conclusion

According to the analysis of the data collected from Phyphox[9], both Guitar 1 and Guitar 2 are almost at par and have similar quality in terms of tone as compared to the standard guitar. Both Guitar 1 and Guitar 2 have similar frequencies to the Standard Guitar when compared in Audio Autocorrelation; the graphs produced by Guitar 1 and Guitar 2 are very similar in nature to that of the Standard Guitar; after Fourier transformation, the peaks of all three graphs are almost at the same frequency. Sustain is the only feature where Guitar 1 and Guitar 2 lag behind, having significantly less sustain than the Standard Guitar. All of this evidence points towards the Null Hypothesis being true. Therefore, the quality of the tone produced by the guitars made from upcycled material is comparable to the quality of the tone produced by the standard acoustic guitar.

4.1. Limitations

1. A device for string excitation to ensure reproducibility could not be created due to a lack of resources. The strings were hit with my index finger, so the force could not be kept constant each time I hit a string.
2. The guitar was kept on a table during the experiment, so some of the energy from the table might have gone into the guitar.
3. Phyphox does not reduce background noise by itself. Therefore, background noise could not be reduced.

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