Digital Signal Processing

UNIVERSITY OF SCIENCE AND TECHNOLOGY OF HANOI

Final Report: Musical Instrument Tuning

GROUP 17

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ABSTRACT

The importance of precise tuning cannot be overstated in the field of music, as it directly affects the overall sound quality and performance of the instrument. Traditional methods of guitar tuning rely on manual adjustments, which can be time-consuming and prone to human error. The integration of DSP techniques provides a promising solution to help analyze the pitch of the instrument signal, helping to minimize the error while tuning.

1. INTRODUCTION

1.1. Overview

This report aims to analyze and optimize the digital signal processing (DSP) techniques employed in musical instruments tuning. The study focuses on the specific requirements and challenges faced by my group in achieving accurate and reliable tuning for our instrument.

Through this report, we will delve into various aspects of DSP-based guitar tuning, including the fundamentals of digital signal processing, the challenges faced by students in achieving accurate tuning, and the implementation of real-time algorithms and algorithms for frequency analysis.

In this project we also implemented an algorithm called a HPS to improve our estimation. We tested all of this with very minimum noise, but our model also works in a noisy environment.

1.2. Guitar Fundamentals and Musical Tuning Method.

The standard tuning for the guitar is E-A-D-G-b-e. The lower E string belongs to the 2nd octave and the higher e string belongs to the 4th octave. Each note has a corresponding frequency (82.41 Hz - 110 Hz - 146.83 Hz - 196 Hz - 246.94 Hz - 329.63 Hz). The guitar is an harmonic instrument and has a harmonic spectrum which means, along with its fundamental frequency of each string, it also has harmonic pitch or overtones with it. These tones are just a whole number multiplied by the fundamental frequency. These overtones could have an amplitude higher than the fundamental frequency which makes it very hard to detect the pitch of the string.

One easy technique that was developed for pitch detection in musical tuning is the Harmonic Product Spectrum (HPS) algorithm.

1.3. Harmonic Product Spectrum (HPS)

The maximum harmonic coincidence for each spectral frame is measured using the Harmonic Product Spectrum (Noll 1969), where R is the number of harmonics being taken into account.

$$Y(\omega) = \prod_{r=1}^{R} |X(\omega r)|$$

Equation 1: HPS equation

The technique first downsampled our original signal by a fraction of a whole number in the frequency domain into the harmonic domain. Each harmonic pitch is then aligned with our fundamental frequency due to it being a multiple of our fundamental frequency. The idea is after multiplying these harmonic spectrum together, we can estimate the fundamental frequency.

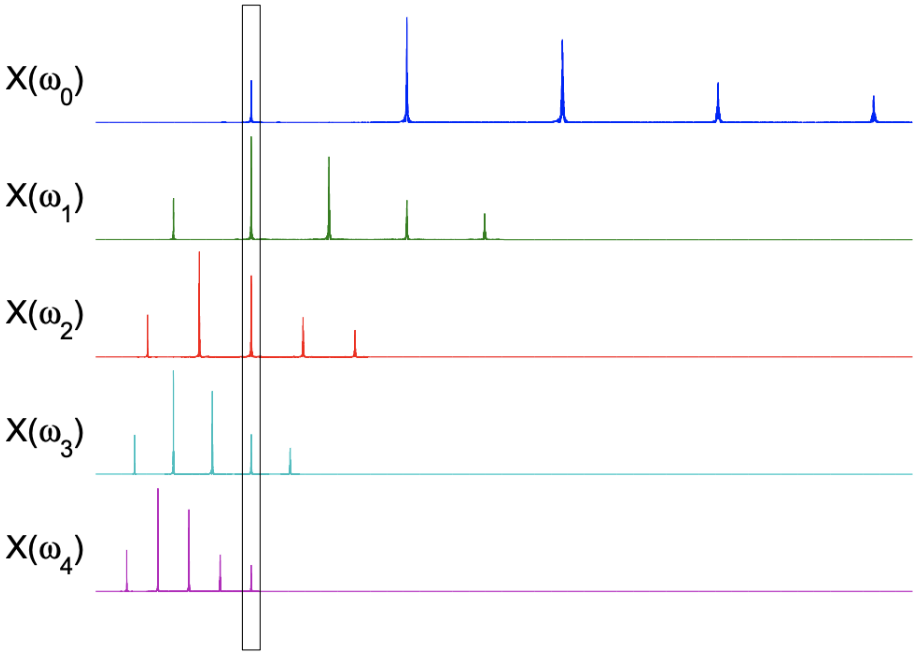

Figure 1: HPS implementation

We look at the maximum amplitude of the harmonic product spectrum to estimate this fundamental frequency.

However the HPS algorithm still has its drawbacks. For example: Octave errors are common if the second peak amplitude below initially chosen pitch is approximately 1/2 of the chosen pitch AND the ratio of amplitudes is above a threshold (e.g. 0.2 for 5 harmonics). The HPS is also better at finding pitch in higher frequency since the lower the frequency is, the harder for us to downsampled the signal. It's recommended that we shouldn't find frequencies that are lower than 50Hz.

Also note that HPS only works with instruments that have harmonic product spectrum. So for example, a piano has high string tensions that cause inharmonicity and it is very hard to implement HPS. Human vocal for example also doesn't follow any harmonic series but instead has formants that cause us to perceive different vowels. Certain instruments have vastly different magnitudes at specific partial intervals. So for HPS to work, we're relying on all partial magnitudes to be non-zero.

In short, HPS is easy to implement, can run in real time and does well under a wide range of conditions. But it also required techniques such as zero-padding for lower frequencies so that the spectrum can be interpolated to the nearest semitone.

In this project, we used a modified version of this HPS.

2. METHODOLOGY AND MATERIALS

2.1. Overall method

Our framework for analyzing pitch is to first sample our audio in real time. We then convert our data to frequency domain via FFT which helps us to analyze the magnitude of the signal. This conversion is taken only using a chunk of 8192 samples in our buffer in order to plot the signal in real time with somewhat less latency and pretty high resolution for our human eyes. It also helps with the estimation of the fundamental frequency. We band passed the signal from 16 Hz to 20 kHz which is the normal human hearing frequency. A modified version of HPS is also used to improve our estimation. This works best in a limited noise environment but for the convenience of the project we also plotted the signal in its normal environment.

The visualization of our system is shown in the figure below.

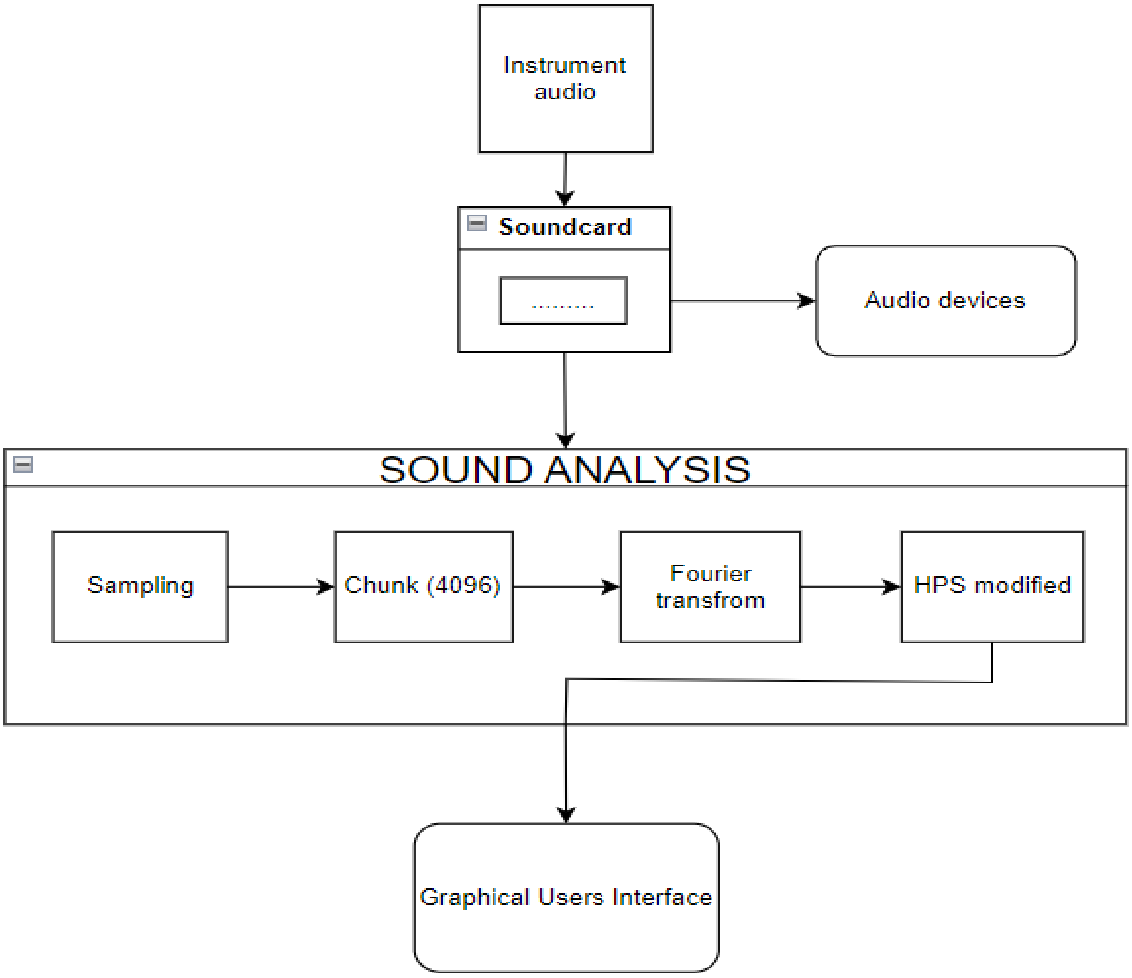

Figure 2: Model diagram

2.2. Modified HPS

In this project we also used a modified version of HPS. Usually after downsampled, harmonic spectrums are then multiplied with each other in order to get a single high peak which shows the fundamental frequency.

Instead of multiplying our harmonic spectrums together, we sum them up. Multiplying our harmonic usually leads to very high peaks which are hard for us to visualize, also we ran into a lot of problems with our python interpreter, it's hard for it to detect the highest value in the harmonic frequency spectrum. So to simplify the problem we sum them up. Since we're only interested in the highest amplitude after summing them up, at the point where the fundamental frequency is, it also results in the highest amplitude since all of the peak values in the frequency domain are added up. We also called this HSS for Harmonic Sum Spectrum. This also works in noisy environments with of course the matter that the noise amplitude is small enough that it won't severely damage our signal frequency or their harmonics.

2.3. Signal data input

With the help of streaming we can then plot the signal in real time. Our instrument input will then be processed. For the demo, we used a Presonus Studio 24c interface to record the signal from our Electric Guitar which has the same standard tuning as other kinds of guitar such as the Acoustic Guitar or the Classical Guitar. The use of interfaces will help us test in limited noise scenarios. We also used the sampling rate of 44.1 kHz which helps us recreate an analog signal up to 22.05 kHz.

3. IMPLEMENTATION

3.1. Graphical User Interface

To make the digital tuner more user-friendly and practical, a graphical user interface (GUI) is developed, allowing users to easily navigate and utilize the application for tuning their guitars. The GUI provides a visually intuitive platform where users can interact with the tuner, visualize the tuning process, and make necessary adjustments.

3.2. Backend results

For the demo we first play a single string of the Guitar. Usually we'll be tuning from the 1st string to the 6th string. Results are pretty promising. For the 1st and 2nd strings which are the higher e and b string. We calculated the fundamental frequency with pretty good accuracy and precision. Unfortunately, the lower the string is the harder for us to calculate the fundamental frequency, but they are still in the range of accepted frequency with some cents off of the required frequency.

This turns out quite a success with the appliance of our modified version of HPS.

Below in the higher e string before and after tuning.

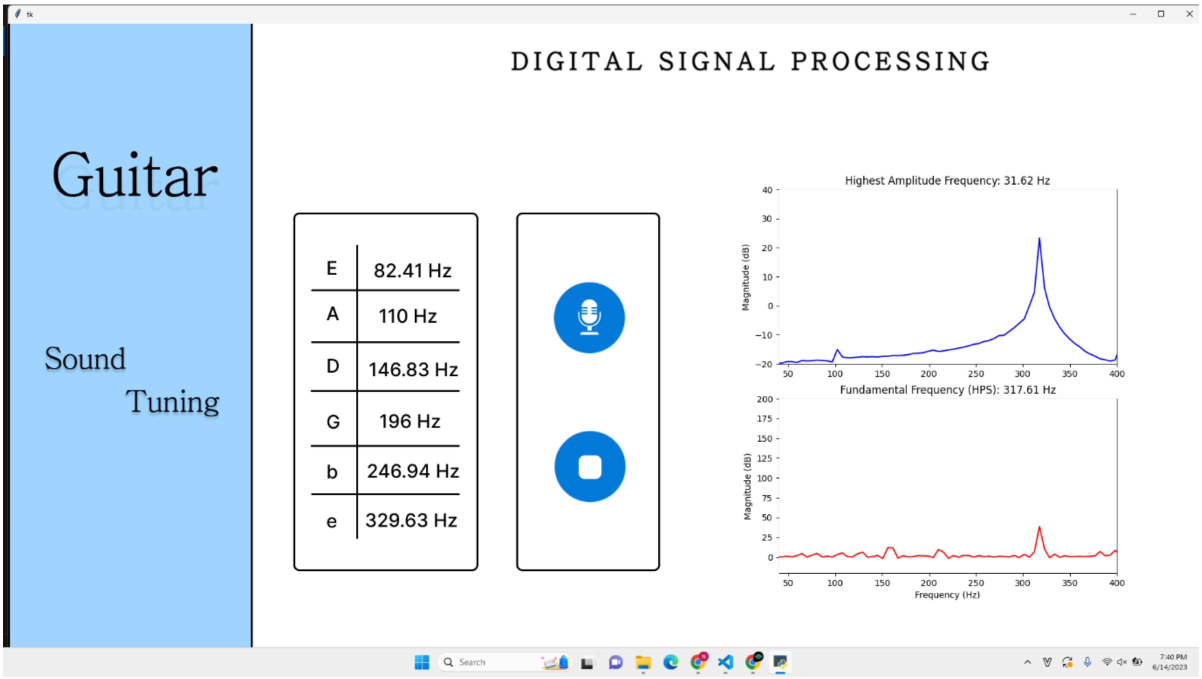

Figure 3: The lower e string before tuning

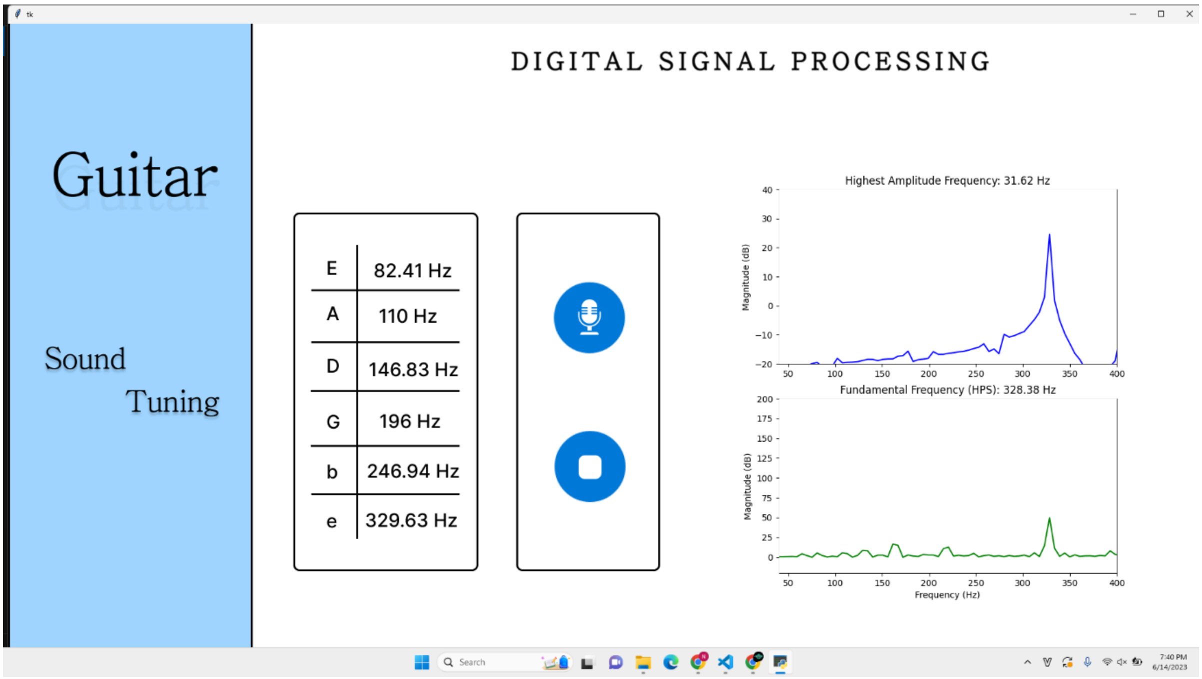

Figure 4: The lower e string after tuned

4. CONCLUSION

The Guitar Tuning Project encompasses the design and development of a digital musical instrument tuner. The project delves into the details of the fundamental frequency of notes. The methodology employed to determine the fundamental frequency, specifically the utilization of the Harmonic Product Spectrum, is thoroughly discussed, shedding light on the accuracy and reliability of the frequency detection process.

Our project also addresses various factors that can affect the detection of the fundamental frequency, including sampling frequency, sampling duration, and background noise present in musical notes. By understanding and accounting for these factors, the project ensures that the digital tuner is capable of providing precise and consistent tuning results across different scenarios.

In conclusion, the Guitar Tuning Project shows various aspects, including the design of a digital tuner, a comprehensive understanding of the factors influencing tuning, the development of an efficient frequency detection algorithm, the implementation of a user-friendly GUI, and the potential for future automation. With these advancements, the project aims to elevate not just the guitar tuning experience but also other musical instruments, facilitating precise and effortless tuning for users of all levels.

5. REFERENCES

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2. https://gist.github.com/carlthome/1e7244e31bd628a0dba233b6dceebaef
3. International Edition: Signals and Systems ALAN V. OPPENHEIM and ALAN S. WILLSKV with S. HAMID NAWAB: 2nd Edition

6. GITHUB AND OTHER DOCUMENT

https://github.com/TGraceAn/DSP_Final?fbclid=IwAR0XhAZI9hcm_6uoNNSn69bTakY5ogyjowb2TsKVt3CZob0yYEhHNJ_dgQw

https://www.canva.com/design/DAFlv6tvmck/qyI64Qpi57yI9n0G1rI4uw/edit?utm_content=DAFlv6tvmck&utm_campaign=designshare&utm_medium=link2&utm_source=sharebutton&fbclid=IwAR3Nc1hJd5kGagUWL45QfPtLhZre-Kw4_wWb4QJ2kIMfUkW1v6DFsmY-Om8