Construction and Harmonic Analysis of a Steel Pan

University of Illinois at Urbana-Champaign

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Acknowledgements

This project would not have been possible without the patient help of Jim Brownfield of the Physics/MRL machine shop.

Also deserving of thanks is Professor Steven Errede, who cut the skirt and provided the necessary motivation, explanations, and Matlab code.

Finally, a special thank you goes to retired band director John Krumm, whom introduced myself and my wide-eyed middle school peers to the steel pan. Without him I never would never have been able to appreciate the beauty of these incredible instruments.

Introduction

The history of steel pan drums begins in the 1700s, when Africans were enslaved on the islands of Trinidad and Tobago. The slaves, uprooted from their homelands, tried and succeeded to maintain some part of their former culture, an effort that manifested itself in hand drums. From the hand drum grew scrap metal drums, from which came the incredibly complicated steel pan. As centuries passed and the slaves regained autonomy, the instrument's popularity grew and grew. Currently, steel pans are most commonly associated with Carnival, an annual two-day event on the islands that celebrates freedom, ritual, and folklore. At Carnival massive steel bands perform, reaching upwards of 100 piece-bands, with soca, calypso, and more resonating from seemingly unassuming metal drums.

My personal interest in steel pan began approximately one decade ago, when I was first introduced to them during a community concert. My grade school band had the incredible fortune to be directed by a pan enthusiast, Mr. John Krumm. Mr. Krumm had been building the steel drum band for six years by the time I was able to join, and he had built up an extensive repertoire of songs. The library included but was not limited to reggae, calypso, soca, and pop. I played steel pan throughout my middle and high school years, performing in the Virginia Beach Panfest twice. I stopped only when I departed for the University of Illinois. During my third year at university I tracked down the contact information for the UI Steel Band, and have been playing with them ever since.

The project detailed in this paper couples my love of steel pan with my engineering background. During this semester I conducted extensive research regarding the physics of the steel pan, referencing various professional sources to expand my knowledge of how the drum works. I also did a brief Matlab analysis of two different mallet types to determine if the thickness of the mallet head significantly changed the resulting sound. Finally, the bulk of this project was actually constructing a steel pan. Building a steel-drum is an incredibly labor and time-intensive process and I was unable to fully complete my amateur pan. Despite this, I made significant progress and will continue the project into the summer.

Physics of the Steel Pan

From a scientific and acoustical perspective, steel pan drums are incredibly complex. During this project I identified three major areas of interest: the orientation of the notes around the well, observed harmonic resonance of thirds, fourths, fifths, and octaves, and different nodes associated with different notes shapes.

1. *Circle of Fifths*

The circle of fifths is a very common musical tool that describes the relationship between the 12 different pitches of the chromatic scale. These relationships correspond to different key signatures and each pitch is one fifth away from its abutting neighbors. A diagram of the circle of fifths is included below as Figure 1.

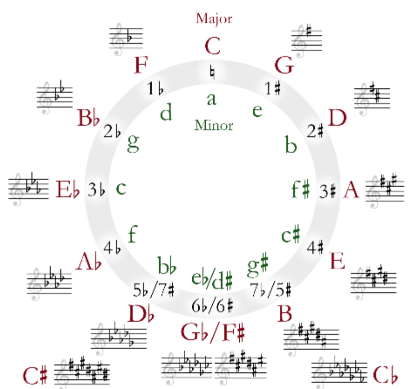

Figure 1. Pythagoras's circle of fifths and associated key signatures.

The circle of fifths was originally developed by Pythagoras and has since been updated by western musical theorists. Alternative temperaments have also been developed, but the circle of fifths remains the most widely used.[1] Interestingly, the inside of the steel pan is oriented in the circle of fifths, following Figure 2.

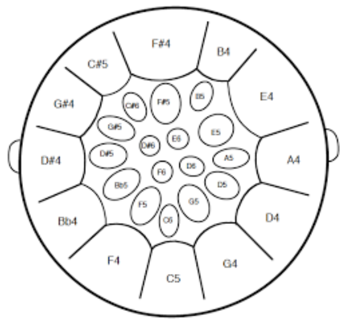

Figure 2. The inside of a steel pan. Note the similarity to the circle of fifths.

The reason the pan is setup in this manner is because of resonance and interference between waves. To avoid harmonics or half-step interference, the notes that are the closest on the musical scale are farthest away from one another physically. This subtle but necessary design criteria ensures clear tones. Resonance is another reason the notes are oriented the way they are within the bowl.

2. *Harmonic Resonance*

Arguably the most fascinating physical aspect of the steel pan is the resonance observed between different notes. As researched by Andrew Morrison of DePaul University, nearby steel pan notes resonate within themselves when played. Morrison observed these resonances with high-speed electronic speckle pattern interferometry (ESPI).[2] Coupling between notes also occurs between the fundamental and the octave, and between perfect fifths. The results of Morrison's ESPI analysis are included are as Figure 3.

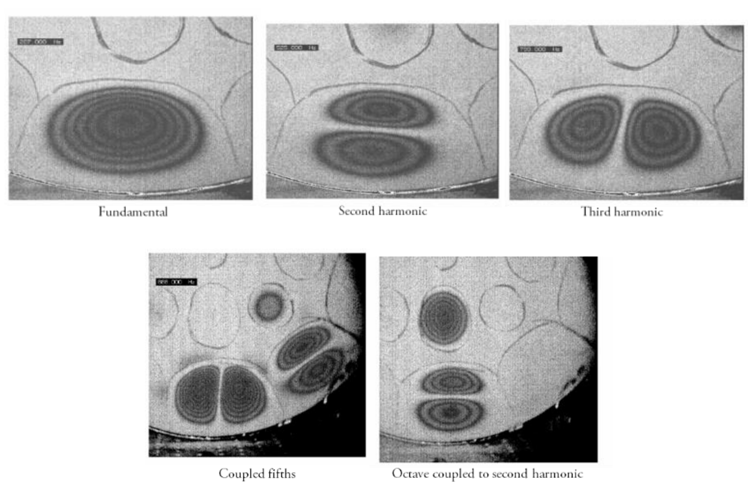

Figure 3. Coupling and resonance observed using ESPI.

This coupling is fascinating and explains much of the so-called "shimmer" associated with Caribbean music. The overtones and coupled notes give the instrument an incredibly distinct sound and this ESPI investigation explains why.

3. *Nodes*

Nodal physics is the third and final aspect of the drum that I investigated. Each steel pan note is shaped differently and different shapes correspond with different sounds. Most notes are trapezoidal, although some the inner notes are perfect circles. In some drums, the notes are even rectangular. From a more technical perspective, the differently shaped notes resonate at unique frequencies and exhibit nodal behavior in different areas.[3] A visual depiction of this is included as Figure 4. The difference that the note shape makes, coupled with the variations at different frequencies reinforces just how complicated this instrument truly is.

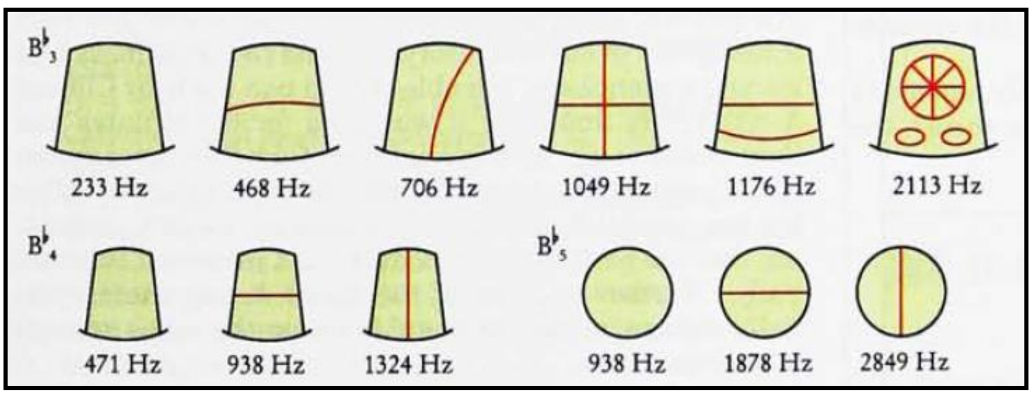

Figure 4. Nodes and modal shapes of three different B-flat notes in the double-second steel pan.

Matlab Harmonic Analysis

The first deliverable of this project was the harmonic analysis of two different mallet heads on the steel pan. My personal mallets were handmade by Craig Lutke of Ibidis Mortem Productions. They are aluminum, eight inches long with a ½" diameter, and are tipped with rubber, surgical tubing. Both ends are tipped, with one end described as "fine" and the other "regular", the regular being marginally thicker than the fine. An image of the tips is included as Figure 5. The fine tips are intended to bring out the notes in the higher register of the pan, while the regular tips are all-purpose. I was curious about this claim and decided to analyze the notes produced with the different tips and compare them to determine the best side. For this project, "best" was defined as producing louder, clearer, and more sustained sound.

Figure 5. Difference in rubber tip thickness between mallet heads.

I used a Matlab wave analysis program to analyze an A major scale played on a steel pan owned by the university. The code was written by Professor Errede himself and analyzed harmonics, amplitude, and overtones of individual notes, among many other qualities. The most important data to my project was amplitude and harmonics. Included Figures 6 are example graphs of an A_4 strike and the amplitude vs. time associated with each tip. As can be seen from the figure, the thinner tip has a marginally higher amplitude, corresponding with a louder sound. Additionally, more harmonics can be observed with the thin mallet graph at higher frequencies, indicating more overtones, associated with the aforementioned "shimmer".

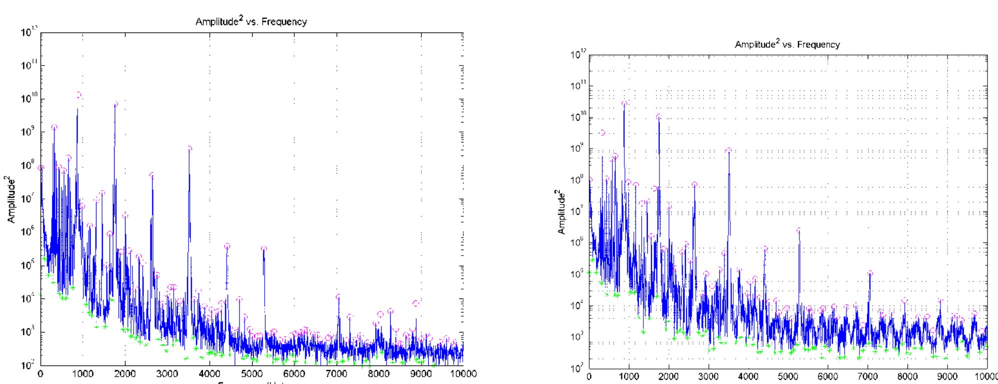

Figure 6. Graph of thick mallet (left) and thin mallet (right) amplitude vs. frequency. Note the clearer harmonics when compared with Figure 6, especially past 7,000 Hz.

After analyzing these graphs, among the many others I decided that the thin mallet heads were actually more favorable throughout the entire octave. Many of the other graphs generated during the wave analysis are included in Figure A1, A2, and A3 of the Appendix.

Building the Pan

The second deliverable was to build a steel pan. Constructing a steel pan is an incredibly labor intensive process. Coupling this with its intricate physics, only professional pan makers can truly craft the instrument well.[4] Despite this, I decided to take on the challenge. The methodology for constructing a pan can be split into six main steps: sinking the head, cutting the skirt, welding and sanding, tracing and grooving the notes, tempering the drum, and tuning it. During the writing of this paper, four of the six steps have been completed, and with much success.

1. *Materials*

   Before the pan could be built, the materials had to first be obtained. Steel pans can be made of many different types of steel with varying thickness, but they all originate from 55-gallon oil drums. Thus, the first step was obtaining an oil drum. I purchased my oil drum from Rural King in Champaign, and attempted to choose one with the least rust, dirt, and grime inside. It is included as Figure 7.

Figure 7. Purchased 55-gallon oil drum with concentric circles.

   A three-pound household hammer was also used during this process, along with a ruler and a rag to muffle the sound. Earplugs and gloves were worn during the majority of this four-step process.

2. *Methods*

I. Head Sinking

The first step was to draw concentric circles to identify the center of the drum, and to develop a template to follow during the sinking process. The concentric circles are included in Figure 7. The sinking process was the most laborious process and took many hours to achieve the desired depth of six inches. During the sinking process the center of the drum stretched so much that it cracked multiple times. Jim Brownfield of the Physics machine shop welded these cracks and assisted me through the entire process.

The drum was sunk from the inside moving inward in circular motions. This slowed the thinning in the middle as the thicker outer rim was somewhat pushed towards the center. After approximately 15 hours of hammering, the final depth was reached. See Figure 8 for before and after photos. After reaching the desired depth, the drum surface was smoothed using small strokes with the hammer.

Figure 8. Early in the sinking process (left), compared with the final result (right).

II. Cutting the Skirt

The next step was the cut the skirt of the drum. The skirt acts as a baffle for the sound (an additional physical complication) and thus the length is very important. The skirt for a tenor pan is approximately 6 inches, and it was cut accordingly, using a HACKZALL saw borrowed courtesy of MRL. The edge was sanded for safety purposes and an image is included as Figure 9.

Figure 9. Cut and groomed edge of the pan.

III. Welding and Sanding

As mentioned, towards the end of the sinking process center of the drum thinned incredibly and tore easily. Many welds were necessary to fix these, and these fixes were also sanded to make the surface more uniform. The uniform surface was necessary to ensure consistency between notes. A picture of the welded and sanded surface is included below as Figure 10.

Figure 10. Sanded and welded inner surface of the cut pan.

IV. Note Tracing and Grooving

The next step was to trace the notes inside the pan. A note template was obtained online from Ulf Kronman's *Steelpan Tuning* document.[5] The notes were placed on the surface of the drum and traced in marker. After tracing, the lines were indented with a flat-head screwdriver. These indents are designed to separate the notes from one another, ensuring only the struck area resonates. During this time the space between the notes was also sunk, to add concavity to the bowl and definition to the notes. Figure 11 gives an impression of the overall look of the pan post-note tracing, and includes an image of the grooving process.

Figure 11. Note templates (left), traced notes (center), and grooving process (right).

To Do: Tempering and Tuning

Thus far, the aforementioned four steps have been completed in the construction process. The next two steps are tempering and tuning of the drum. Tempering of the drum increases its Young's modulus, a measurement used to predict the elasticity and stiffness of a material. Increasing this property increases the hardness and resonance of the instrument and it greatly affects its material properties. This in turn affects the final step: tuning.

While tuning is not as physically demanding as head-sinking, it is likely to be the most time consuming step. Tuning a steel pan is an iterative process and involves lightly hitting an individual note area up and down until the desired pitch is reached. The adjacent notes are subject to the same methodology. Inconveniently, when the adjacent note is tuned it bends and affects the previous note, meaning the latter is now out of tune. Tuning is typically done in a circle around the drum, raising and lowering each note repetitively until the pitches are all correct. Tuning is the final aspect of steel pan construction, and I plan on officially completing the project over the summer.

Conclusions

In conclusion, this project was as successful was I anticipated it would be. The initial research taught me a lot about the instrument itself and expanded both my knowledge of and love for the steel pan. The harmonic Matlab analysis resulted in answers conflicting with the marketed slogan and I personally decided that the thin head was more suitable at all frequencies. Finally, the construction of the pan itself was reasonably successful, considering the immense time and dedication typically required to produce a steel pan.

References

1. Blackburn, T. *Alternate Temperaments: Theory and Philosophy*, 2004.

2. Morrison, A. 2010. *Characterization of Coupled Vibrations in the Caribbean Steel pan*. DePaul University, 2010.

3. Rossing, T. *Music From Oil Drums: The Acoustics of the Steel Pan*. Physics Today, American Institute of Physics, 1996.

4. Kronman, U. *Acoustic Function of the Steel Pan*. Stockholm, Sweden, 2015.

5. Kronman, U. *Steel Pan Tuning*. Arlov: Musikmuseet, 1991.

Appendix: Other Matlab Graphs

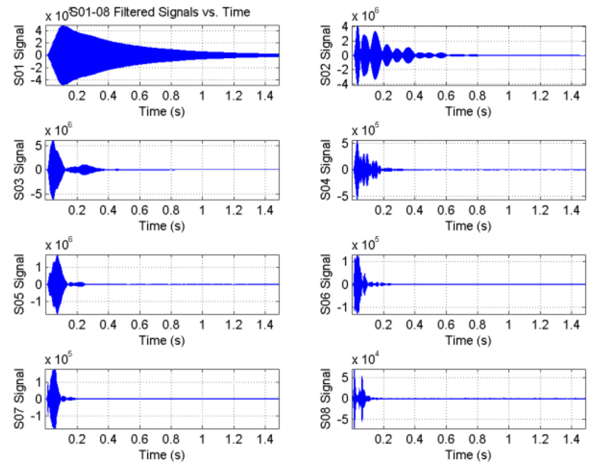

Figure A1. Thin mallet signals over time.

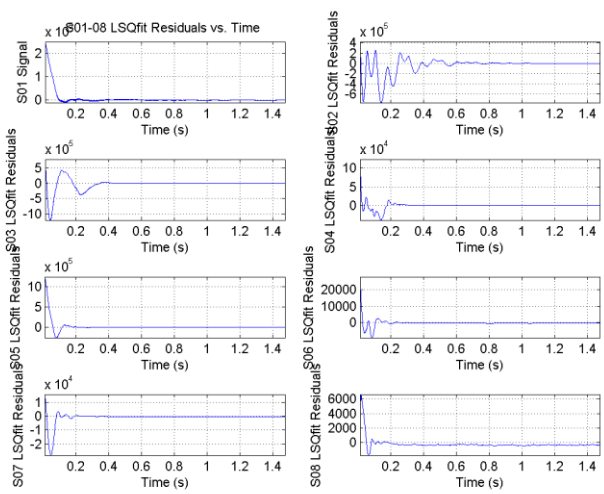

Figure A2. Thick mallet residuals over time.

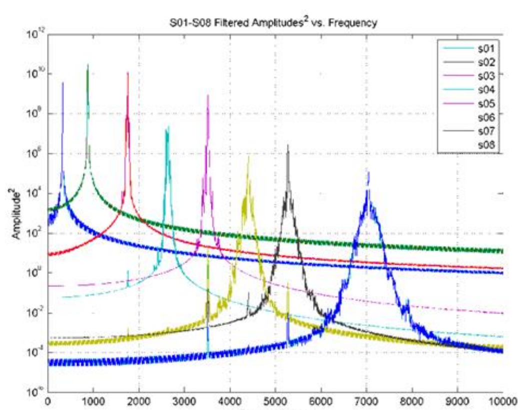

Figure A3. Thin mallet amplitudes vs. frequency.