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ARTICLE

Laser Tuner: A Novel Approach to Pitch Detection on a Drumhead

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When we think of drums, pitch is rarely a dimension that is emphasized. However, pitch is just as important as any other component of percussive music. The pitch of a drum is important for keeping the drum in tune with itself and other drums, and, in the case of variable pitch drums such as timpani, staying in tune with the rest of the ensemble. Even though pitch is integral to the cohesion of the music, there are no commercially available methods of pitch detection that can satisfy all three of these contexts. As a result, I have designed a system that can detect the localized pitch of the drumhead, allowing the user to be confident that every part of the drumhead is at the same pitch. This system can also be used to know the pitch of the drum as a whole, giving musicians the utility to quickly and accurately change the notes of the drums.

BACKGROUND

There were three important concepts to understand when developing this project; the physics of sound and reflection, circuit design, and the relationship between pitch and frequency. The physics of reflection describes how the signal is created, circuit design describes how the signal is prepared, and the relationship between pitch and frequency describes how the prepared signal is processed into useful data.

The rate that drums vibrate is directly related to their pitch. As they vibrate, they create areas of high and low pressure, known as compression and rarefaction, respectively (Diamantini, 2003). The pitch describes how quickly these areas of differing pressures occur. Therefore, the faster the drumhead vibrates, the faster the pressure zones are created, and the higher the pitch of the drum. Thus, if we can measure how fast the head is vibrating, we can measure the pitch it produces.

To measure this vibration, a laser and a photoresistor were used. The light from the laser was reflected off of the drumhead and onto the photoresistor. According to the law of reflection, the angle that light strikes a surface is the same angle at which the light is reflected (Fitzpatrick, 2007). As a result, if the surface moves, the angle relative to the surface moves, and therefore the reflected beam will also move. The photoresistor can quantify this movement of the laser. Using electronic components, the movement can be converted into a signal that an arduino microcontroller, the device used to find the frequency of the signal, can understand.

Ohm's law is an important fundamental tool for working with electronics. It states that voltage, (V / volts) is equal to current (I / amps) multiplied by resistance (R / ohms) V = I x R (Hooge, 2016). This principle is essential for deciding what components to use in a circuit. My circuit was based on four main subcircuits: the voltage divider, the non-inverting amplifier, the DC offset, and the low-pass filter. When combined, these components functioned to send power through to the photoresistor, return a signal, then amplify and clean the signal to be interpreted by the arduino.

The frequency of a sound wave determines the pitch of the sound wave. To find the pitch using musical notation, a constant is required. In this case, if we know that A = 440 Hz, pitch is logarithmic, and the unit used is cents (1/100 of a semitone), the equation becomes:

$$\log\left(\left(\frac{1}{1200}\right)\left(\frac{f}{440}\right)\right)$$

From here, the musical notation is relative to A = 440 Hz. Every 100 cents is a semitone away from this pitch, so it is easy to calculate the pitch (Hall, n.d.). This can be used to take the frequency presented by the microphone, and turn it into a letter note that is more conducive for tuning instruments.

OBJECTIVE

Percussionists often have to tune their drums, which can be an arduous task and requires a lot of experience to achieve a consistent pitch all the way around the drum. The objective of this project is to create a device that limits these problems in an easy to use package. The system will use a reflected laser to quantify the vibrations of the drum head. When used around the drum, it will be easy to find an equilibrium throughout each tuning position.

DESIGN

This design consists of two main components: the microphone and the tuning circuit. The microphone consists of a 3D printed frame with holes for the laser and receiver that sit parallel to the drumhead. Some simple circuitry connects the laser and receiver to a ⅛ inch female jack. It has a standard female microphone thread, and is attached to a rim-mount microphone clip. The tuning circuit consists of a custom amplifying circuit based on the tl082 operational amplifier. It includes various subcircuits

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to help prepare the signal for the arduino. The circuit is soldered on a shield for the arduino, and the whole unit is secured in a 3D printed enclosure. In the current design, there are holes for input/output to connect the tuner to a computer where the interface is located (Figure 1).

RESULTS

When the device was constructed and connected to the computer, and the laser reflected back onto the photoresistor from a large tom drum, it produced a visible signal. A series of simple tests were performed to verify that the electronics were working as intended. When the potentiometer was adjusted, the amplitude of the signal also adjusted proportional to the potentiometer. When light was passed under the photoresistor, a large spike was seen in the signal. Next, the drum was struck approximately 5 cm away from the rim of the drum directly in front of the protruding laser of the device, and then repositioned and struck again. This replicates the process of tuning a drum by ear. When struck, the device detected frequencies such as those seen in Table 1.

DISCUSSION

The results of this design were very promising. A signal was successfully received from the reflected laser, amplified, processed, and graphed on a computer. A frequency was found which seemed to correlate with the frequency of the drumhead. Each time the frequency was played and then the drum was struck, the frequency audibly matched one of the lower tones in the drum. When applied to different parts of the drum, the frequency changed when the frequency of the drum changed. From a hardware perspective, this design seems functional. However, due to a limited knowledge of computer programming, a single frequency could not reliably be obtained from the drum. Instead, a string of frequencies were produced. Upon inspection, it became apparent that these frequencies were all members of the harmonic series of the drum. This means that they are all related to the fundamental frequency by a simple ratio. By reproducing the acquired frequencies using an oscillator, the pitches acquired were identical to those produced by the drum.

This design met all of the criteria of the initial project. The arduino housing is compact, taking up just enough space to fit the arduino inside. The use of a screw means the laser can be rotated to adjust its position. The microphone does not touch the head of the drum, and instead clips onto the rim. Consequently, it has no effect on the vibration of the drum. Once the microphone is posi-

Table 1. Frequencies detected by Arduino at 2 separate positions The frequencies above 20 Hz were then played using a pure tone generator and an oscillator, which audibly matched the frequencies produced by the drum when struck in the same position.

Position 1 (Frequency, f / Hz)	Position 2 (Frequency, f / Hz)
83.07	39.09
20.68	20.23
41.54	9.93
40.61	9.93
80.80	11.27
80.80	76.77
19.40	18.99
19.28	76.62
40.44	60.86
20.02	20.16

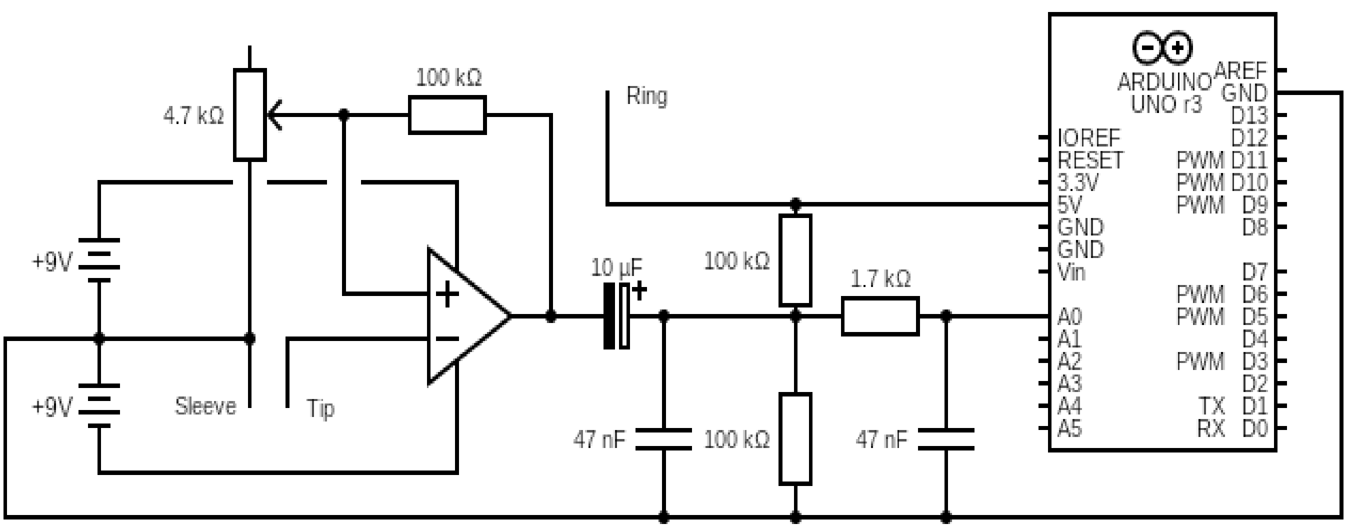

Figure 1. Amplifying circuit.

tioned and turned on, it automatically sends information through to the computer.

FUTURE PLANS

Although this prototype worked, it is still not finished. There is a need for custom software that will take the string of frequencies and produce a usable reading, which could be achieved by either improving the current code derived from a guitar tuner or by performing a Fast Fourier Transform (FFT) on the signal. An FFT would show the fundamental frequency of the signal and that could be converted into a musical pitch (Heckbert, 1998). To further improve the project, the microphone element will be adapted so that the laser is modulated as it leaves. Then, the receiver can also be modulated. By finding the doppler shift between the incoming and outgoing laser, the signal can be obtained (Purdue Physics, n.d.); this has the benefit of not needing a reflective surface.

CONCLUSION

This project aimed to demonstrate that using lasers to quantify sound can be a useful technique for tuning drums. Not only did this prototype capture the frequencies produced at a localized point on the drumhead, but it is also the only device that is specifically designed to be used to tune drums with such precision. Commercially available options, such as a torque key or conventional guitar tuner, fall short in various aspects of tuning the drum, such as still requiring fine tuning by ear, and not taking each tuning position into account. Once the software has been further designed and refined, comprehensive data collection and analysis can be performed to quantify the precision and accuracy of this device. At this point, the technology can be shrunk down to a more portable, and commercially viable product. The laser tuner solves a common problem in a small, easy to use manner with inexpensive components that function much more reliably than current systems.

REFERENCES

Diamantini, T. M. (2003). The Physics of Sound: How We Produce Sounds. Retrieved from http://teachersinstitute.yale.edu/curriculum/units/2003/4/03.04.04.x.html

Fitzpatrick, R. (2007, July 04). Law of Reflection. Retrieved from http://farside.ph.utexas.edu/teaching/302l/lectures/node127.html

Hall, R. (n.d.). Pitch and Frequency. Retrieved from http://people.sju.edu/~rhall/SoundingNumber/pitch_and_frequency.pdf

Heckbert, P. (1998, January 27). Fourier Transforms and the Fast Fourier Transform (FFT) Algorithm. Retrieved from http://www.cs.cmu.edu/afs/andrew/scs/cs/15-463/2001/pub/www/notes/fourier/fourier.pdf

Hooge, C. 20.2 Ohm's Law: Resistance and Simple Circuits. In College Physics. OpenStax CNX. Aug 22, 2016 http://cnx.org/contents/031da8d3-b525-429c-80cf-6c8ed997733a@9.35

Purdue Physics. (n.d.). Modulation of Light. Retrieved from https://www.physics.purdue.edu/webapps/index.php/course_document/index/phys570P/1684/25/14317

BIBLIOGRAPHY

Alhota, G. A. (2014). Sound Waves Transmission via IR Laser The Laser Microphone Device. Retrieved from https://www.academia.edu/13549827/Sound_Waves_Transmission_via_IR_Laser_ The_Laser_Microphone_Device?auto=download

Chounlakone, M., & Alverio, J. (2002). The Laser Microphone. Retrieved from http://web.mit.edu/6.101/www/s2017/projects/jalverio_Project_Final_Report.pdf

Electronics Tutorials. (2018, April 28). Ohms Law Tutorial and Power in Electrical Circuits. Retrieved from https://www.electronics-tutorials.ws/dccircuits/dcp_2.html

Ghassaei, A. (2017, October 27). Arduino Audio Input. Retrieved from https://www.instructables.com/id/Arduino-Audio-Input/

Nave, R. (2003). Voltage Divider. Retrieved from http://hyperphysics.phy-astr.gsu.edu/hbase/electric/voldiv.html

ZACH FRASER

My name is Zach, and I am a grade 12 student from Cape Breton, Nova Scotia. I'm passionate about music, especially percussion, and am very active in the music community in my city and Nova Scotia. I've even produced an Extended Playlist with a local ukulele group! I hope to go into engineering sciences and become an acoustical engineer. This is my second time at the national fair, and I am incredibly excited to be here again. It is a great opportunity, and really reminds me how amazing youth in Canada are. My project, The Laser Tuner, was inspired by my philosophy teacher who described a similar technology used for surveillance in the early 20th century. I just applied it to a relevant context: drum tuning. I hope to continue refining my project, and with some luck achieve a patent and develop a commercially viable tool. If you are interested in creating a project, I suggest reflecting on what you do on a daily or weekly basis. Often times there are things you do that could be improved. These can be great projects! Fun fact about me, I am also a black belt in Tae Kwon Do!