EE300W
CRITICAL DESIGN REVIEW:
OPTICAL THEREMIN
“THE SQUIRREL WHISPERERS”
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Abstract

In this project, we have designed and constructed an optical theremin using a combination of analog circuitry and LabVIEW code. Through a transimpedance amplifier, we convert user-controlled photodiode current into a voltage readable by the myDAQ measuring system. This signal is conditioned and tuned using our LabVIEW assembly. An audio signal is produced and emitted from the myDAQ. By operating the photodiodes, the user can control the volume and pitch of the audio signal as well as control the volume and pitch ranges using the LabVIEW front panel display. The audio output can also be tuned to play at set frequencies using the auto-tune feature.

Introduction

Many people are amazed by pianos that “play” themselves without any physical touch. Similarly, a theremin is an electrical music instrument that allows a user to create music without making physical contact. A standard theremin consists of two separate electromagnetic circuits which control the instrument’s pitch and volume. In this experiment, we designed an optical theremin. Unlike a regular theremin, whose operation is based on electromagnetic fields, an optical theremin is controlled by the intensity of light it detects. We implemented our theremin using two photodiodes that control the magnitudes of the sound’s amplitude and frequency.

The control of the device relies on effective LabVIEW code and a complementary circuit. The LabVIEW VI is able to interpret this input and manipulate it to produce an output signal with variable frequency and amplitude. Users are able to control attributes such as amplitude and frequency, and may exercise our auto-tune feature which tunes the signal to defined frequencies of music notes.

The design process allowed the group to implement a systematic approach while adapting the design continually. This project strengthened our teamwork skills and the understanding of LabVIEW. The completed device allows any individual to create unique music and auto-tune the sound for a polished creation.

Rationale

Our approach to construct the optical theremin involves the interface of physical circuitry with LabVIEW code. Photodiodes act as current sources that supply a current proportional to the intensity of light detected. The user influences the photocurrents manually by interfering with the amount of light that shines on the diodes. The circuit converts the photocurrents into voltage signals that are read by the myDAQ.

To add more specificity to our design, we created a 3 level block diagram (see Figure 1A) to illustrate our design process. We accomplished the transformation by dividing our task into its two distinct components at the N=1 level: the circuit and the LabVIEW code. The circuit transforms our input current from the photodiodes into a readable voltage range for the myDAQ to provide to LabVIEW to condition the signal.

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The two input currents for the level of volume and pitch each require an amplifier to send a respective analog signal to LabVIEW. This process is illustrated in our N=2 level, which subdivides our physical circuitry into volume and pitch stages. The LabVIEW code is also divided into two recognizable parts, the signal conditioning and the auto-tuning. In the signal conditioning stage, the circuit voltages are transformed into frequency and amplitude signals. The user can implement the auto-tune sub-VI to produce sound that is more pleasing to the ear. The auto-tune sub-VI reads the frequency generated in signal conditioning and rounds it to the nearest frequency associated with a note in the C Major scale.

**Implementation**

The circuitry is responsible for converting the current from each photodiode into a voltage that can be read by the myDAQ. To accomplish this, we implemented a TL074 Op-Amp in a transimpedance amplifier configuration (see Figure 3A). In this configuration, the diode current is directed along the inverting input and a resistor connects the inverting input and the output pin. Through Ohm’s law, the current travels through the resistor inducing a voltage on the output pin which will be read by the myDAQ. On the breadboard, the photodiodes were spaced far apart for practical reasons. A complete bill of materials for this project can be found in Appendix A, Figure 2A.

According to their respective datasheets, the myDAQ accepts voltages up to ±10 V and the photodiodes’ output currents range from 16 to 35 µA. Using this range of currents, we chose 270 kΩ resistors to produce a voltage range of 4.32 to 9.45 V. In practice the voltages produced under these conditions were less than 1 V, meaning that the photodiodes were outputting lower currents than rated. We increased our resistor values to 10 MΩ, which yielded inputs of up to 8 V in full light. This wide range facilitates the quantization and normalization of data during signal conditioning.

The LabVIEW code consists of several sub-processes that help transform the circuits’ output voltages into sound. Once voltage samples are taken, they are normalized to comply with the parameters found on the front panel. The normalized samples are then converted to either a frequency or an amplitude. From this point, the user can choose to pass the frequency samples through the auto-tune function. The frequency and amplitude samples then feed into a Simulate Signal function, where they are converted into a sinusoid, and finally the sinusoid is written to the myDAQ’s TRS port. The VI block diagram of Figure 1B illustrates this process.

Changes were made to our original VI design to eliminate sonic discontinuities and clicking sounds. Periodic gaps in the output sound resulted from implementing two separate DAQ Assistants for the circuits’ inputs, which decreased the rate at which LabVIEW processed the data. By performing both “read” operations with the same DAQ Assistant, sonic discontinuities were eliminated. Other modifications made to the LabVIEW code focused on streamlining the VI. We organized parts the auto-tune and frequency normalization operations into separate sub-VI’s (see Figures 2B & 3B). We also optimized the LabVIEW embedded functions to increase the program’s efficiency. For example, we replaced Case structures with Select functions.

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because Case structures have significantly more overhead. The result of these modifications fixed the processing time errors and eliminated the clicking sound.

Another change we made involved adjustment of the sampling rate of the DAQ Assistants. Initially, our sampling rate was set to 1 kHz, which resulted in an aliasing effect. At higher frequencies, the sound output of the myDAQ was distorted. The timing rate was adjusted to 48 kHz, a common sampling rate of digital audio, which eliminated all aliasing. Our signal input range was chosen to be $\pm 10\text{ V}$ to accommodate the circuits’ complete range of output voltages. The signal output range was constrained to $\pm 2\text{ V}$, the maximum voltage tolerated by the myDAQ’s 3.5 mm TRS connector. Captures of the properties of the DAQ Assistants are included in Appendix B.

On the VI’s front panel (Figure 6B), the user is able to select a feature called “Auto-Tune”. This Sub VI takes the input frequency values and compares it to a large array of values generated by a shift register (see Figure 2B). This VI contains an array corresponding to a specific note on a scale, ranging from C$_1$ to B$_1$. This array is saved to a shift register array and then scaled by a factor of $2^n$ to account for pitch increase. The integer $n$ represents a different octave. This final array is compared with all the input frequencies. The values of the input frequencies are rounded to the closest value in the array, resulting in an auto-tune.

**Conclusion**

As established in this report, our optical theremin design meets all high level and low level design requirements. This was confirmed by the successful demonstration of our device in the laboratory. Our integrated hardware and software design provides an efficient and user-friendly method for creating and controlling music through light. This experience strengthened our teamwork skills and our technical skills.
Appendix A

Figure 1A: Three-Level Block Diagram

N = 0
Inputs → Transformation → Outputs

N = 1
Inputs → Circuits → LabVIEW → Outputs

N = 2
Light → Frequency Circuit → myDAQ → Conditioning → Auto-Tune → Audio
Light → Voltage Gain Circuit

Figure 2A: Bill of Materials

<table>
<thead>
<tr>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>TL074 Op-Amp</td>
</tr>
<tr>
<td>(2) 10 MΩ Resistors</td>
</tr>
<tr>
<td>(2) Photodiodes</td>
</tr>
<tr>
<td>NI myDAQ</td>
</tr>
<tr>
<td>Speaker or headphones</td>
</tr>
<tr>
<td>Breadboard</td>
</tr>
<tr>
<td>Copper Wire</td>
</tr>
</tbody>
</table>
Figure 3A: Circuit Diagrams
Appendix B

Figure 1B: Theremin VI Block Diagram

Figure 2B: Auto-Tune Sub-VI Block Diagram

Figure 3B: Frequency Conversion Sub-VI Block Diagram

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Figure 4B: DAQ Assistant 1 (Inputs)

Figure 5B: DAQ Assistant 2 (Output)

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Figure 6B: Front Panel Display