Electric Violin Audio Processor

ECE 445 (Spring 2022)

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Introduction

Problem Statement

Current electric violin pickups tend to fall in one of two categories. Inexpensive pickups are readily available for either acoustic or solid-body violins, but produce a sound quality which is sometimes described as “tinny” or “nasal”, and whose harmonic content is too limited for a significant amount of sound design to be carried out. These typically have one piezoelectric sensor for the entire bridge. High-quality pickups produce a “rich” sound with well-balanced harmonic content which is well-suited for use with effects pedals and other sound design tools, but are expensive and often hard to obtain due to low production volume. These typically have at least one sensor for each string.

(The sound quality of pickups is highly subjective. An example of the “nasal” sound of an acoustic violin piezo pickup is demonstrated in [1].)

We have done some prior work with 3D printing electric violin bridges having one sensor for each string. It is difficult to ensure that each string has a similar sound quality or volume by changing the mechanical design of the bridge alone, except by trial and error. Furthermore, the type of strings used can drastically affect the sound of the instrument; for example, steel strings are characteristically “bright” and tinny, while Thomastik Dominant synthetic strings are known

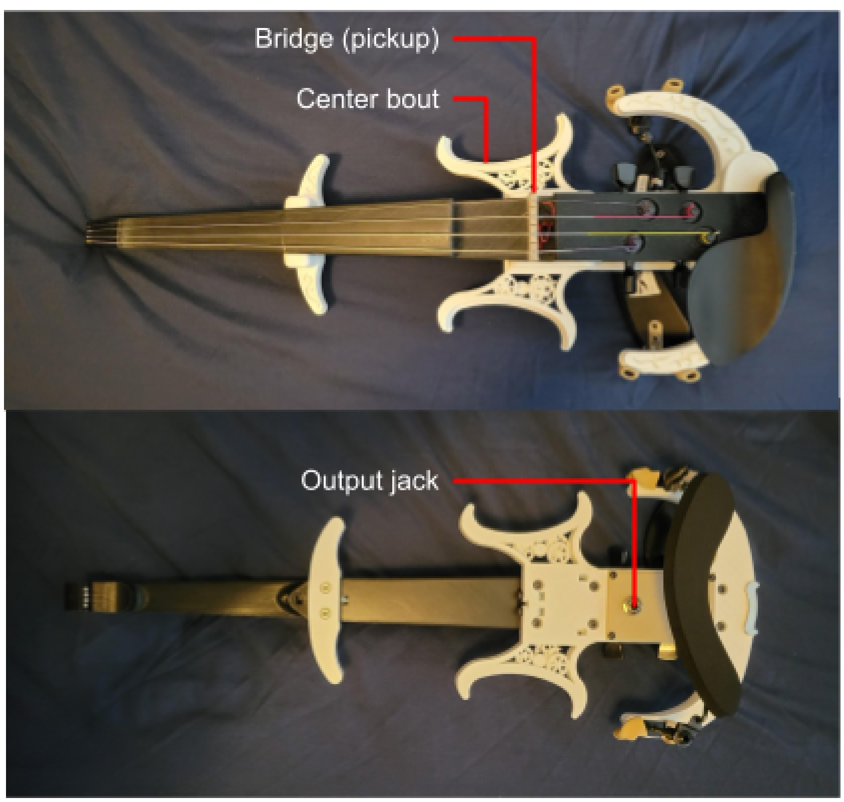

Figure 1. The Mina electric violin.

for having a “thin”-sounding E string whose timbre contrasts with that of the other three strings. (This is likewise a very subjective assessment, but [2] shows an example of discussion on this topic.)

Figure 1 shows the relevant parts of the Mina electric violin. The design is publicly available online [3]. Figure 2 demonstrates the intended integration of the solution into the violin body; the processor is to be housed in an enclosure attached to the right center bout.

High-level Requirements

1. Be able to adjust the volume of each string using a gain between negative infinity (mute) and +3 dB, and filter the string signal using a bandpass filter with variable bandwidth and center frequency between 100 and 6000 Hz.
2. Be able to save, overwrite, and recall two sets of audio parameters (gain, filter center frequency and bandwidth, and volume) using the user interface.
3. Fit in a space of 150x100x50mm, which is roughly the size of the decorative center bout on the Mina electric violin. The PCB should be housed in an enclosure attached to this part of the violin.

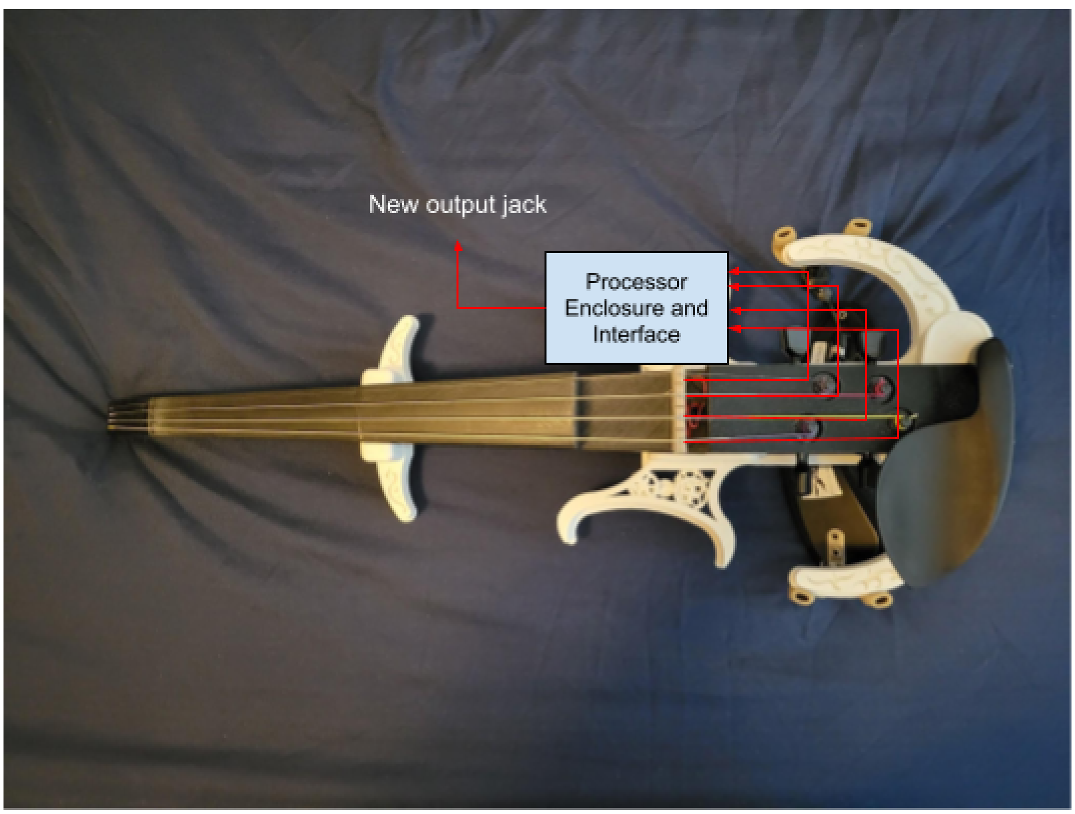

Figure 2. Sketch of proposed solution.

Design

Figure 3 shows the block diagram for the proposed solution. For the sake of brevity, the audio processor is only shown once, but the same process is applied to each string independently. The same is true of the rotary encoders and lightbars for each audio parameter to be handled, and of the pushbuttons and LED indicators.

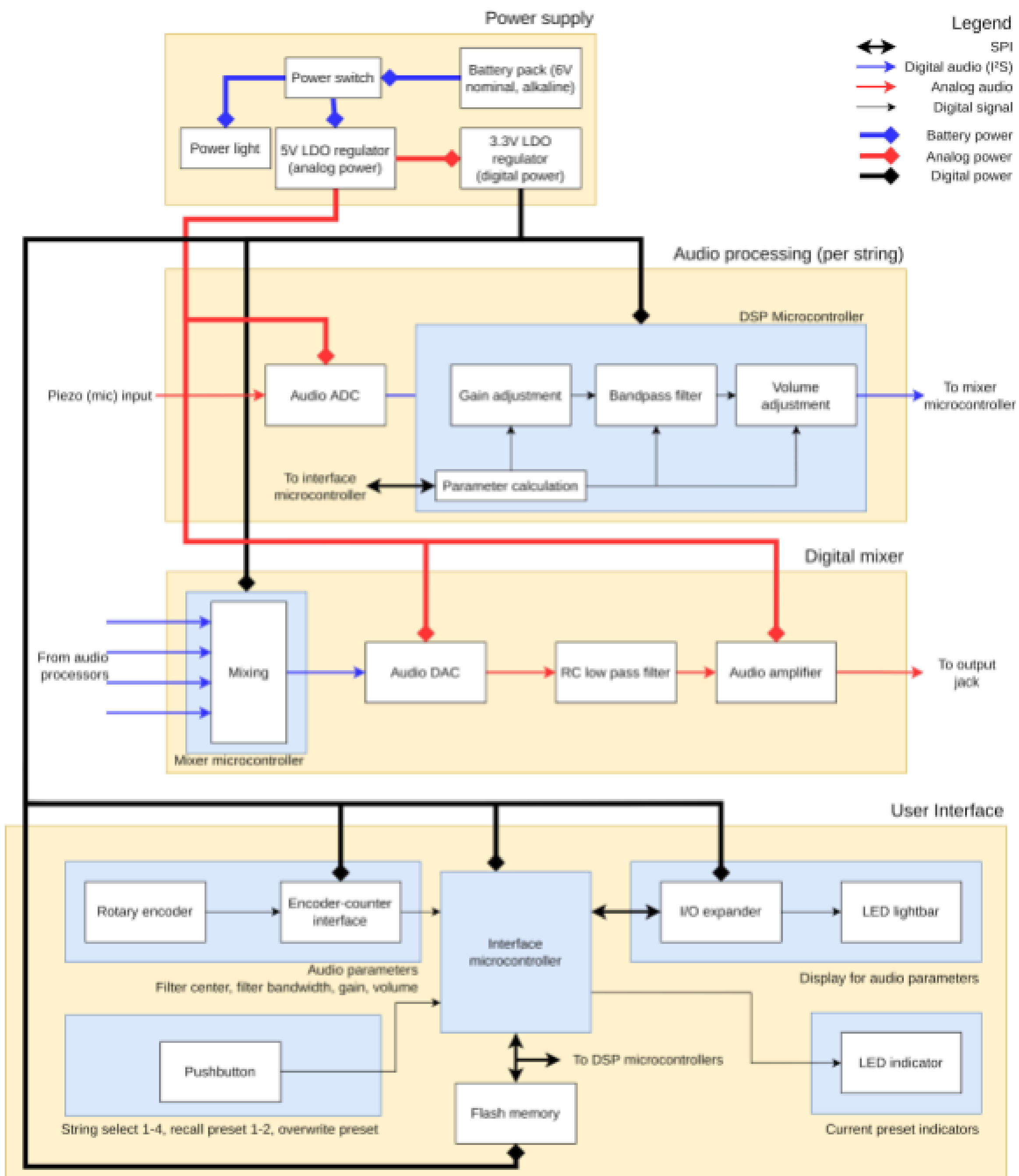

Figure 3. Block diagram of proposed solution.

Subsystems

Power

This is the power supply for the audio processor, which should regulate 6V nominal battery power to 5V (±0.2) analog and 3.3V (±0.1) digital power. Additionally, this system should be able to supply 150mA (±10) of current in total to the other subsystems.

Audio Processor/Mixer

This subsystem applies gain/volume adjustments and filtering to the input signals from each piezo pickup, then mixes the four string signals to the final instrument output.

For each string, the processor should have a bandpass filter with variable center frequency (between 100 and 2000 Hz) and bandwidth. Also, the processor should have a variable gain control both before ("gain") and after ("volume") the filter stage.

The audio processing microcontrollers should have SPI connectivity with the interface microcontroller as a bus responder.

The mixer should combine the four processed audio signals to be sent to the instrument output jack. The mixer microcontroller should have four audio inputs and one audio output over I^2S, as well as SPI connectivity with the interface microcontroller as a bus responder.

User Interface

This subsystem provides controls for the user to change the gain, filter center frequency, and volume for each string, and to save combinations of these parameters as presets. To do this, the interface should have knobs to control the variable gain/volume, filter center frequency, and filter bandwidth.

The interface should also have buttons to select the string whose audio parameters are being modified, and a set of light bars to suggest to the user what the current settings are. (The light bars need not be extremely precise.)

The interface should have an external SPI flash memory for saving presets, and be able to communicate with the audio processing microcontrollers over SPI as a bus controller.

Tolerance Analysis

The project as a whole is very complicated, similar subjects have been written about to earn the author their PHD. When it comes to DSP, to complete the process accurately and efficiently can be very complicated. Many equations will have to be taken into account for our design to be able to correctly implement our desired features. Our parameters and algorithmic functions will have to be carefully calculated while still allowing for tolerances due to the nature of the project and the requirements imposed. The initial sensors as well as the ADC will both be required to be heavily tested and fine tuned to allow for the signals that are being processed to be as true to the original sound as possible. There is the inherent risk of lots of signal noise or crosstalk between the strings, resulting in convoluted signals. The real time DSP process is also quite complex, especially when utilizing an approach where there are more avenues for hardware failure due to the multiple different ICs that will be used. While with our design we aim to simplify and strengthen the DSP process through the utilization of a modularity approach, this is a method that has less proven references to use and therefore will also be quite a complicated process requiring a lot of attention and fine tuning. The algorithms to complete such a process have been heavily researched[4][5][6][7], but as our implementation aims to progress electric violin design and sound creation/emulation, there are the possibility of pitfalls. While the entire project has difficult problems throughout each subsection, the high-tier, efficient implementation of a modular approach to DSP of each string individually will be of utmost importance. The aspect of modularity is inherently beneficial in this case as the problem can be broken down into simpler parts and approached as such, but this does not guarantee success when it comes to a process that requires such accuracy in terms of even the most minute details and aspects.

However, the feasibility and functionality of such a design can be proven, no matter the outcome of the overall design process, through mathematical analysis and simulation of the algorithms and methods we are going to implement. Regardless of overall functionality, the risks in this situation are effectively mitigated through the amount of deep research that we have already done into the feasibility of such an approach, as well as the the relation of our approach to other methods that have already been proven feasible, the proof of our concept's feasibility through mathematical analysis, and the ability to be able to simulate and prove functionality of our approach using already created software, or any software that we may create.

We believe our tolerance analysis for the risks of a critical subsystem failure have been fully contemplated, and we are confident that we could prove feasibility of our concept and implementation right now if it were to come into question.

Ethics and Safety

This project presents few safety concerns. All voltages used are 6V or less, using alkaline battery chemistry. Once placed in an enclosure, there would be no meaningful contact between the user and the circuits inside.

This project presents few significant ethical concerns, although similar prior work does exist. Notably, the Strados electric violin, created by ZETA Violins [8], uses an internal active preamplifier system which allows the volume of each string and the overall gain to be adjusted manually [9]. ZETA refers to this pickup system as "patented" on their website, but does not list a patent number; additionally, we could not find a relevant patent upon searching for "ZETA violin" in Google Patents. Therefore, we cannot immediately confirm whether this patent exists, let alone if the product is still under patent protection. This may pose an obstacle if we choose to choose the project in the future.

Our pickup design is inspired by Richard Barbera's design, "Resonant pick-up system" [10]. The patent expired over a decade ago, and since our bridge is not carved of wood, it is unlikely that our design would be infringing on this patent anyway.

Citations

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