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Reflective Optical Pickup For Violin

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ABSTRACT

We present here the development of optical pickup for acoustic violin. Unlike other optical pickups, this one works in a reflective mode, which is potentially less intrusive. This pickup, aimed principally at pitch tracking, uses a modulation technique to improve the signal-to-noise ratio, and limit artifacts of the ambient light.

Keywords

Violin, pitch tracking, optics, pickup, optical microphone

1. INTRODUCTION

The research presented here is a part of our on-going projects on "augmented instruments", and in particular a part of the "augmented violin" project [1]. This project concerns the development of various gesture capture systems for the violin (initially inspired, from a technology point of view, by the work at MIT on *hyper-instruments* [2]). Previously, we reported on a capture system for bow dynamics [3][4] that has been used in live performances.

One of the project's goals is to propose solutions compatible with any acoustic violin, avoiding any type of alteration (including on the acoustic sound). Recent developments do not take into consideration this constraint and therefore cannot be used in this context.

Here we report on developments concerning pitch tracking, which is an important feature for controlling various sound processes or performing score following. Pitch determination is generally difficult on violin, especially when polyphonic playing is used. Operating pitch tracking for each string separately can greatly simplify this task. Moreover, there is strong interest in capturing string vibration directly to avoid various acoustic effects due to the violin's resonance and other external sounds.

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2. RELATED WORKS

Axon [5], Roland [6] and recently Gibson [7] have developed guitar and bass pickups and electronic systems that enable pitch tracking. A magnetic pickup is mounted under each metal string and each audio signal that comes from the strings can be converted into MIDI or USB messages.

However, in the case of the violin, such pickups cannot be used because the strings are not made from a magnetic alloy (the E-string is often made of a magnetic alloy but there is no rule for the others). Piezo pickups [8], inserted in the bridge, are an alternative solution but this implies either replacing the original bridge or integrating the pickups directly in the violin, as it is the case for Zeta violins [9]. This solution cannot be put in place with our constraints, where musicians use their own instruments that cannot be altered in any way.

Another solution is the optical pickup. In this case, a light beam is sent to the string and is modulated by the string vibration. The resulting light is measured by a photo diode or a phototransistor and can be electronically converted into an audio signal. LightWave Systems [10] and Ron Hoag [11] already sell guitars and basses that use optical pickups. Concerning the violin, Dan Overholt [12] developed high quality pickups for his "Overtone Violin".

Nevertheless, all these cases make use of optical pickups in a transmission mode, i.e. the string is located between the beam emitter and the receiver. This implies a setup that reduces the playing capabilities. Moreover, this configuration is difficult to install without making important modifications to the violin structure (placing them on the bridge for example, as it is the case for the Overtone violin).

An elegant solution makes use of optical pickups in a reflective mode, where the emitter and receiver are placed on the same side of the strings. This allows one to place the sensors under the strings. Therefore, there is nothing that physically limits the bow's movements.

Nevertheless, this solution is technically difficult, as described by Freed [13] in his attempt at such a technique for the guitar. He did not pursue this project due to small and variable levels of reflected light and interference with the ambient light. Other difficulties are connected to possible string bending and possible occlusion of the pickup by the hand.

We propose here a modulation technique solution that overcomes most of these problems, i.e. low light level and ambient light interference.

3. LIGHT MODULATION

To no surprise, our first attempt showed that the direct use of reflected light on the string is particularly disturbed by ambient light. To overcome, we implemented an IR modulation technique. The IR beam emitted is modulated using a 50kHz carrier. The string vibration modulates the amount of light reflected back to the IR photo receptor (a photo transistor), as described by the following equation:

$$s(t) = A(t) A_0 \sin(w_0 t + phi_0 + phi_1) + b(t) \qquad (1)$$

where:

- $s(t)$ is the resulting signal,
- $A_0 \sin(w_0 t + phi_0)$ is the modulation signal with $w_0 = 2\pi \cdot 50\ khz$ and phi_0 the initial phase of the signal,
- $A(t)$ is the resulting amplitude modulated by the movement of the string and phi_1 the phase shift due to the system,
- $b(t)$ is the noise introduced by ambient light and electronic.

$A(t)$ is the interesting part that we want to extract and transform in an audio signal. We can use a synchronous demodulation circuit. $s(t)$ is demodulated by multiplying it with the 50kHz carrier $A_1 \sin(w_0 t + phi_0)$, we obtain s_d, the demodulated signal:

$$\begin{gathered} s_d(t) = A(t) A_0 A_1 \sin(w_0 t + phi_0) \sin(w_0 t + phi_0 + ph \\ + b(t) A_1 \sin(w_0 t + phi_0) \end{gathered} \qquad (2)$$

$$\begin{gathered} s_d(t) = \tfrac{1}{2} A(t) A_0 A_1 \cos(phi_1) \\ -\tfrac{1}{2} A(t) A_0 A_1 \cos(2 w_0 t + 2 phi_0 + phi_1) \\ + b(t) A_1 \sin(w_0 t + phi_0) \end{gathered} \qquad (3)$$

The non-modulated part of $s(t)$ is 50kHz shifted up in the spectrum and the modulated part appears around 0Hz and 100kHz. Therefore we can isolate the low frequency part of s_d by a strong low pass filter at approximatively 10kHz (not too low to preserve harmonics from the violin) to get:

$$\tfrac{1}{2} A(t) A_0 A_1 \cos(phi_1) \qquad (4)$$

and transform it into an audio signal.

The phase shift phi_1 has to be as small as possible to maximize its cosine.

4. SYSTEM ARCHITECTURE

The schematic of the system is described in Fig. 1, summarizing the different steps explained in section 3.

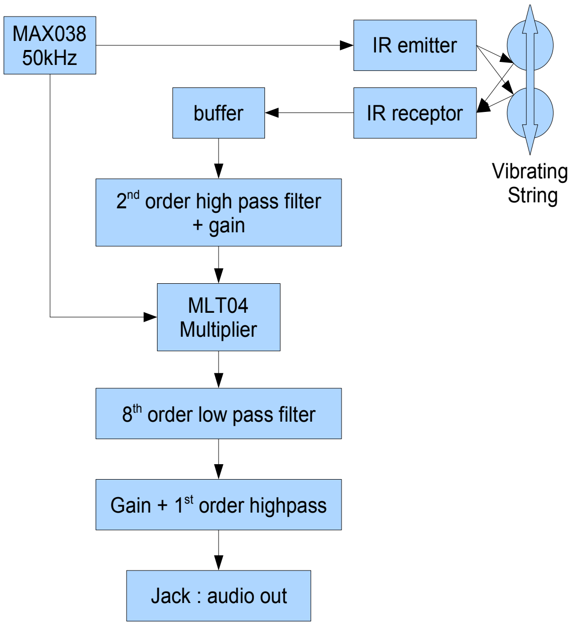

Figure 1.

The whole system is composed by 3 electronic boards :

- the pickup board holding four optical devices and an operational amplifier driving the four signals,
- the main board,
- a power supply board.

4.1 Pickup board

A Kodenshi SG-2BC reflective sensor is mounted under each string. The SG-2BC is a reflective sensor that combines a GaAs IR emitting diode (IRED) and a high-sensitivity phototransistor in a sub miniature ceramic package. Each sensor is mounted on a planar support that can be oriented by three small screws and springs to insure exact positioning under the string (Fig 3). These supports are mounted on a removable mechanical system, designed by Alain Terrier (Fig 2), held under the fingerboard.

As already pointed out, this system should not alter the violin or modify the acoustic sound of the instrument. The system is designed to be easily removable (ideally the musician should be able to use his/her own violin). Three screws are used on each side and two epoxy pads are inserted between the screws and the fingerboard to prevent any scratches on the fingerboard.

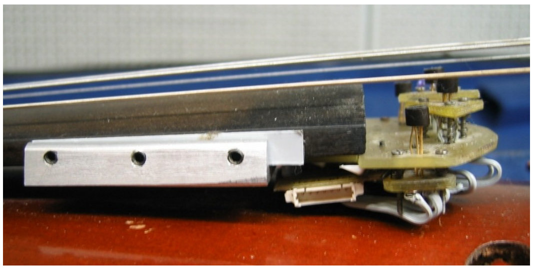

Figure 2. Side view of the pickup board

The position of the sensors is particularly important. We choose to position them as close as possible to the fingerboard in order to take advantage of the greatest amount of string vibration. However other choices are possible and are discussed in the last section of the paper.

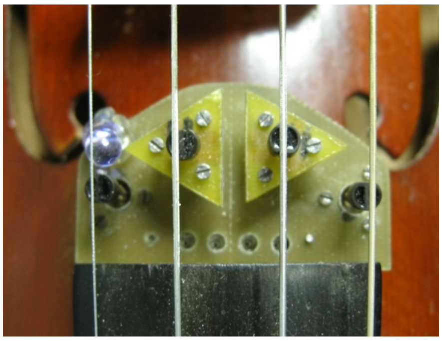

Figure 3. Top view of the pickups

An IR Led was added to the Kodenshi emitter for the E string in order to significantly increase the amount of modulated light emitted, therefore increasing proportionally the amount of reflected light.

The signals coming from the sensors are buffered by an operational amplifier and sent to the main board using a 7 wire shielded cable.

4.2 Main electronic board

The main board has three functions: 1) generating the modulation signal, 2) demodulating the incoming signals from the pickup board, 3) transforming the incoming signals in audio asymmetric signals.

4.2.1 Modulation - demodulation

We use a MAX038 waveform generator from Maxim IC to generate a 50kHz sinus. This signal is routed to two paths:

- the base of a transistor that drives the current through the IR emitters : sine signal from 0 to 100 mA,
- the synchronous demodulation circuit.

The demodulation is carried out using a MLT04 from Analog Devices. The MLT04 is a quad multiplier that performs the following operation:

$$Out = \frac{Input_1 * Input_2}{2.5} \quad \text{(volts)}$$

Each incoming signal passes through a high-pass filter in order to keep only the 50kHz frequency and then through a gain stage to make maximum use of the components' dynamics.

As shown in equation (4), the amplitude of the resulting signal is multiplied by $\cos(phi_1)$ that results of the phase shift due to the electronic system. It appears that phi_1 is very small and so $\cos(phi_1)$ is close to 1. The board includes two stages of all-pass filter aimed at shifting the phase of the reference synchronous demodulation signal.

4.2.2 Filtering and Audio Outputs

The signals coming from the demodulation are rich in high frequencies and need a strong filtering. Each signal passes through a 8th order low pass filter to eliminate the frequencies of 50kHz and above.

The 8th order filters are made using the MAX274 chip from Maxim IC and added resistor to set up the frequency and Q.

Those signals are then buffered, with a gain stage, through an operational amplifier and low pass filtered to eliminate common mode. The outputs are asymmetric audio signals. The gains found at all levels of the component chain have to be set for each string to allow maximum amplitude for the output signals without any saturation through the signal path.

5. TESTS

5.1 System use

We found that the system does not disturb the instrument: the acoustic sound of the violin and the playing techniques are not affected. Therefore, the system has a good potential for broad acceptance by musicians. The pickup board can be easily removed and the entire electronic system fits in a metal box set close to the musician.

5.2 Test patch

To be used with a computer, the system requires a sound card with 4 audio inputs. For the test we used a Motu 828 connected by firewire to a Macintosh G5 running a Max/MSP patch.

For the tests, we recorded the four signals that come from the optical pickups. A fifth audio signal from an acoustic microphone (close microphone specially designed for violin) was also recorded in order to compare the two different types of signals.

We tested the pitch tracking using the Max/MSP yin~ object, implemented at IRCAM by Norbert Schnell and based on an algorithm proposed by de Cheveigné and Kawahara[14]. Other pitch tracking objects such as fiddle~ [15] have been also tested.

Each audio signal is preprocessed to assure the best quality according to the *a priori* knowledge that we have on the signal (compression and band pass filter according to the attainable notes for the considered string) and is then routed into a separate yin~ object.

5.3 Results

The first results show that the audio signals can be retrieved with a certain noise, but this noise does not affect the results of yin~ object outputs.

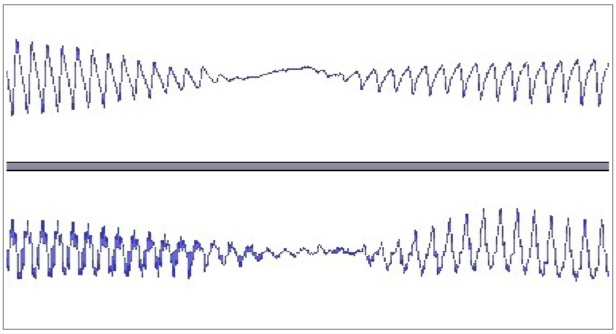

Figure 4. Waveform on the G string (top : G-string optical pickup, bottom : acoustic microphone)

Figure 4 shows the waveforms of the signals that were recorded during a test. This figure displays the transition between two different notes (upbow and downbow).

The waveform of the signal coming from the optical pickup is a good illustration of the typical stick and slip forms of the vibrating string excited by the bow. The second waveform shows the acoustic signal recorded with a microphone. As clearly seen on the transition, the acoustic microphone track contents additional spectral components due to the resonance of the violin body. This highlights that pitch tracking can be easier by capturing the string vibration directly.

Figure 5 shows the outputs of yin~ objects for each optical pickup and for the acoustic microphone. Each note composing the chords is correctly determined from each monophonic optical pickup. On the opposite, the pitch tracking failed with the acoustic signal when the chords are played. This example demonstrates the utility of this optical pickup in the case of polyphonic playing.

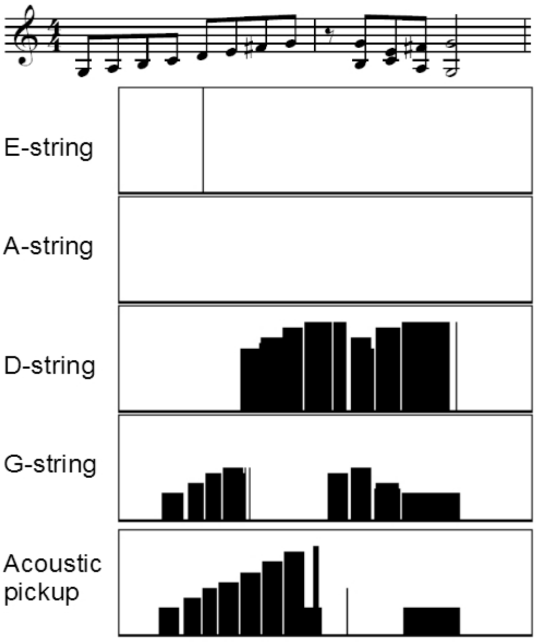

Figure 5. Estimated pitches from yin~ objects for a simple score containing chords

5.4 Issues

We found a higher crosstalk than expected between the pickups, which origin might be explained by either a mechanical crosstalk at the level of board or by an electronic crosstalk. Further investigation need to be performed to clarify such artifacts that can certainly be reduced.

The main issue is, as expected [13], potential perturbation in the optical signal due to the bow. For example, a noise burst appears when attacking the note close to the pickups. Also, there is a change in the optical signal when the bow passes just over the pickups. In this case the amplitude of the modulation signal is reduced causing some noise in the pitch tracking. This could be partially solved by a better positioning. The optical pickup could be placed very close to the bridge. In such a case such disturbance would occur only when the musician plays *ponticello.*

Finally, note that these optical pickups are aimed at performing pitch tracking and not to perform any type of "clean" amplification. The optical pickups "sound" appear to be quite noisy if listen through speakers. This is partly due to noise at the photo transistor level and relatively poor electrical characteristics of the electronic components used for this prototype.

6.CONCLUSION – FUTURE WORK

This development demonstrated that an optical reflective technique can be used to sense string vibration, and in particular in the case of the violin. The use of modulated light solves, to some extend, the perturbation of ambient light. This first prototype was found usable for pitch tracking. As discussed, the main limitation concerns possible perturbation by the bow passing over the pickups that should be improved in the future by a different positioning.

7.ACKNOWLEDGMENTS

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