Musical Applications of New, Multi-axis Guitar String Sensors

Adrian Freed, Osman Isvan
adrian@cnmat.berkeley.edu,
CNMAT, UC Berkeley
1750 Arch St., Berkeley, CA 94709
http://www.cnmat.berkeley.edu

Abstract

The development and application of new optical, piezoelectric and variable reluctance transducers is described for polyphonic stringed instruments especially the guitar.

1. Introduction

The perceptual salience of the longitudinal vibrational mode of the nylon strings of the "classical" guitar has been recently demonstrated by software simulation (Duruöz, 1997). The asymmetry of the coupling of vertical and horizontal displacement modes to bridge and finger-board is also well established from acoustic considerations (Weinreich, 1977, Weinreich, 1979). These observations suggest that multi-axis transduction is necessary to capture the expressive potential of the guitar in a form amenable to musically useful transformation and synthesis.

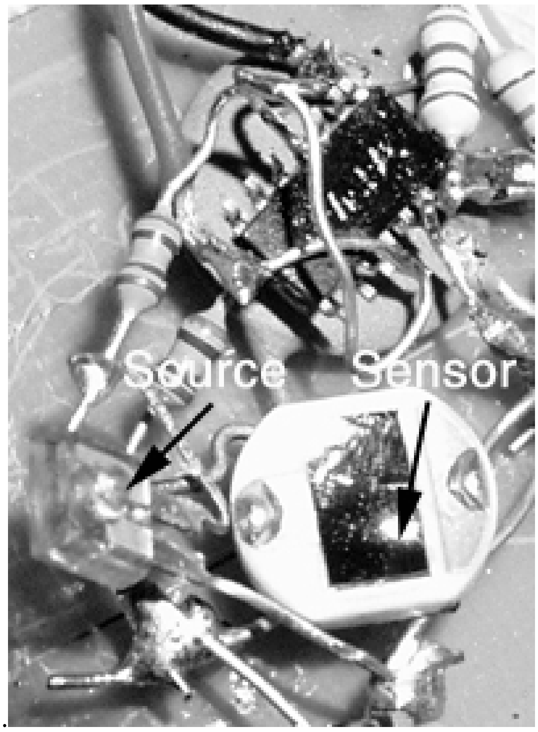
Current transducers for the guitar are most sensitive to motions perpendicular to the top plate and most guitars are equipped with a transducer that captures motion of all the strings as a single electrical signal.

We describe the development and application of new, multi-axis, multi-string optical, magnetic and piezo-electric string transducers.

2. Optical transduction

We have experimented with two different approaches to sensing string motion optically: interruption and reflection. An interruption-based sensor was developed by the first author twenty years ago that demonstrated many seductive qualities. The basic approach is to sense a moving shadow of a light source cast by the string onto the sensor. Note that this is similar in design to the approach Gulbranson uses for sensing organ and piano key position (Freed and Avizienis, 2000). The dynamic range of this transducer system is very high and transducer cross-talk is low, allowing for good results when installed close to the bridge.

Unfortunately important playing techniques such as palm-damping are hampered when a light/sensor pair has to be placed on opposite sides of the string and so the interruption approach is generally rejected by guitarists. Note that certain guitars such as National Resonator instruments (Brozman, 1994) are built with a protective metal strip over the strings at the bridge, frustrating easy palm damping and suggesting a limited application of the interruption optical approach



A reflection-based sensor operates by sensing light reflected from a source on the top plate below the string. Our preliminary work on this strategy revealed so many problems that we abandoned this approach in favor of the methods described below.

We note the difficulties here to guide future researchers tempted to explore this method. The primary problem is that the amount of reflected light is very small and highly variable. The reflecting surface is round, uneven (in the case of the wound bass strings) and made from a variety of metals and alloys with widely different optical properties that vary over time as corrosion and oxidation occurs.

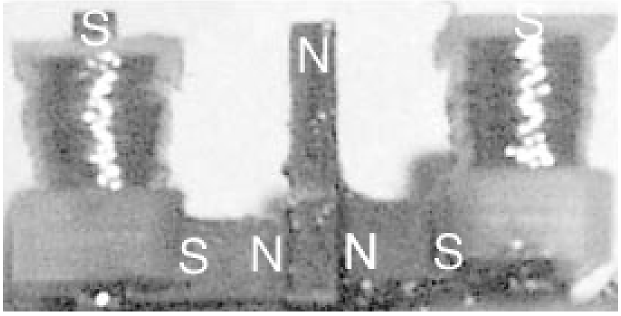
The low level of light compounds another problem: the sensor surface, also on the top plate of the guitar, is exposed to extremely high levels of ambient light. Our attempts to mitigate this effect with an intervening infrared filter were only partially successful due to the further loss of dynamic range attributable to the low transmissivity of the filter even at the peak response frequency.

Finally, various essential playing techniques, principally string "bending", move the strings across the sensor surface, requiring transduction close to the bridge, a common location for string/finger or string/pick interaction. These interactions completely obscure reflected light and sometimes for great lengths of time. For example the preparation of the thumb-pick for a bass string "snapping" used extensively in country blues playing (Patton, 1992) would obscure the sensors for more than 100mS before string/pick contact.

3. Variable Reluctance Transducer

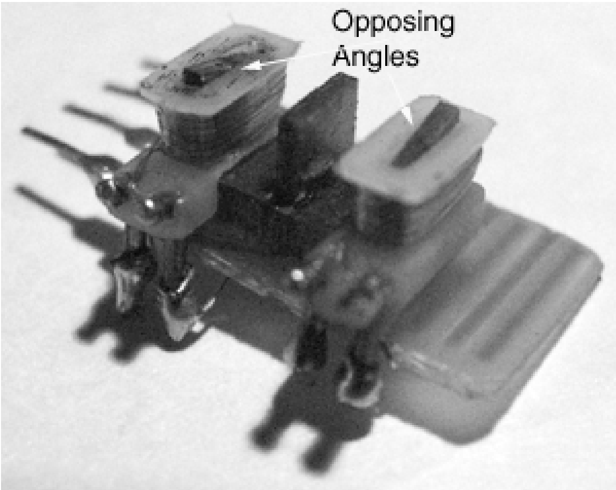
Variable reluctance transducers are the predominant type in electric guitars. The standard monophonic transducer uses a single or double coil around pole pieces for all six strings. Since no effective shielding is available for magnetic fields special, rare-earth magnets are required to focus the magnetic fields to separately transduce string motion for each string. Since the focused fields narrow the effective motion range to be transduced, these hexaphonic pickups are usually placed between the bridge and first conventional pickup in retrofit applications. This constrains the size of the pickup and results in a very high number of small coil windings to achieve a satisfactory output level.

Starting from the basic constraints and design principles of hexaphonic pickups we have developed a new pickup that can be used to independently estimate vertical and horizontal string motion.

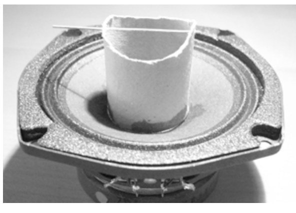


The pickup uses two coils around pole pieces of the same polar organization. Between these coils is a third pole piece of opposite polarity resulting in a two-ring field pattern with common flux lines at the center.

Using pole pieces with a laterally asymmetric geometry we have created a pickup where perpendicular motions produce in-phase output in each coil and lateral motions result in out-of-phase signals. By summing and differencing the two pickup output signals a good estimate of horizontal and vertical motion can be obtained.



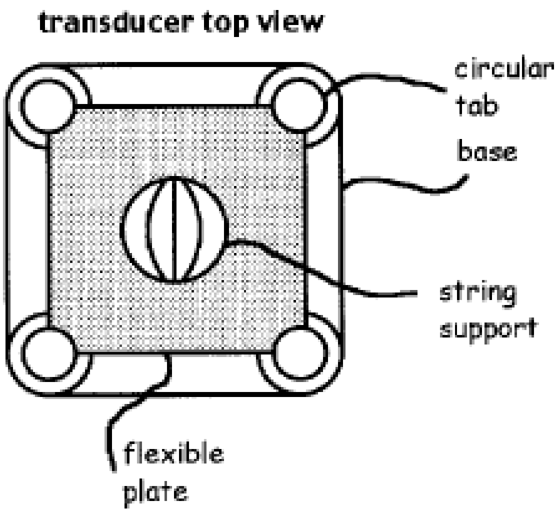
To test this pickup design we mounted a paper clip to a cardboard cylinder glued to a loudspeaker cone.

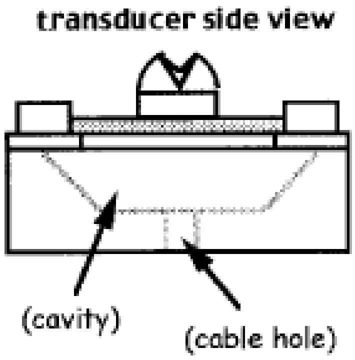


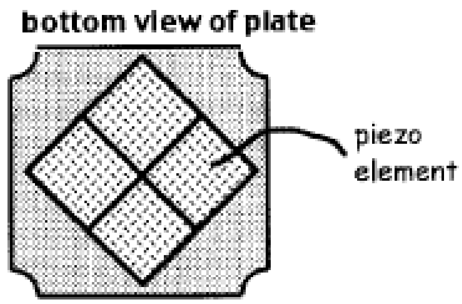
This allowed us to confirm the linearity of the pickup for moderate excursions of the "string" and also to observe the independence of the motion estimation on each axis.

4. Piezoelectric Transduction

We are developing a 3-axis piezoelectric pickup because reluctance modulations from longitudinal string vibration modes are very hard to measure and magnetic pickups don't work on nylon-stringed instruments. The principle of this pickup was pioneered by Richard McClish of RMC and uses an array of piezoelectric sensors bonded to a brass plate. The sensors respond to bending of this plate which is placed on a quadrangle of posts at the bridge. By using 4 carefully placed piezoelectric transducers we exploit different bending modes in the plate that are excited according to the axis of the pressure vector exerted at the center of the plate by the string.







5. Applications

5.1. Introduction

An important feature of the guitar is the coupling of energy between strings. This occurs mainly at the bridge, although the compliance of the neck means that some of this "crosstalk" between strings is attributable to coupling at the frets or nut. The coupling is sometimes viewed as a desirable feature and is exploited in certain musical styles especially when "open" tunings are used. The amount of coupling may be controlled by palm damping or stopping strings with the right (and sometimes left hand). In the applications described below crosstalk complicates signal processing so we have explored the idea of using the parallel-to-the-bridge-motion output of the transducers to reduce crosstalk. The idea is to exploit the fact that top plate and bridge motion is constrained to be mostly orthogonal to the bridge. We used a pair of magnetic two-axis transducers on strings separated in pitch by a fifth and an octave and confirmed that coupled vibration is significantly different in amplitude on the two axes: at least 12 dB.

5.2. Sound Effects

We are developing a large and growing suite of sound processing modules for hexaphonic pickups. These "sound effects" often benefit from a well-isolated signal from each string. For example, applying non-linear distortion to the signals from each string separately, we achieve the desirable bandwidth broadening and harmonic enrichment associated with "fuzz" without the problems associated with cross-modulation partials.

Another class of effects that benefits from good isolation involve dynamic gain changes, i.e., noise gates and compressor/expanders. These effects depend on a reliable energy estimate from each string.

5.3. Parameter Estimation and Pitch Prediction

The most important problems in signal processing for string instruments are the fast and reliable estimation of pitch and identification of plucks (Smith, 1994). Sukandar Kartadinata, a visiting scholar to CNMAT, made an important contribution to the pluck detection problem by demonstrating a fast, reliable method that takes advantage of existing pitch estimates (Kartadinata, 1996). Spectral parameters may also be efficiently computed when a good pitch estimate is available.

Robustness in the face of noise, crosstalk and transients is a major difficulty since pitch estimation errors are so disastrous for the performing musician (Burnett and Gambino, 1996). Adaptive cancellation of signals from the two and three-axis transduction of string motion is being explored to minimize crosstalk and noise.

When the three axis pickup is completed we will develop a low-latency pitch estimation system based on exploiting the fact that longitudinal compression waves propagate faster in a string than lateral traveling waves.

6. Future Work

In the second phase of our research project we will refine the magnetic and piezoelectric pickups described here by installing them on different types of guitars. We will also explore a new optical method for pressure sensing at the bridge, and ways to integrate sensors into the strings themselves.

We have processed the multi-axis sensors using commercially available A/D convertors, i.e. MOTU 24i. The signal conditioning and cabling is unwieldy and impractical for widespread use requiring some 24 pairs of balanced cable for the piezoelectric transducer. We look forward to integrating the A/D conversion close to the pickups and transmitting the result digitally through a standard such as GMICS (ref) which supports 16 channels of data at 96kHz and therefore can be adapted for 24 channels at 48kHz. We have already developed the digital hardware to support this (Freed, et al., 2000).

7. Acknowledgements

The authors greatly appreciate the support of Gibson Guitar Inc, the State of California DIMI program and RMC.

8. References

B. Brozman (1994), *The History and Artistry of National Resonator Instruments*: Centerstream Publications.

I. S. Burnett and P. M. B. Gambino (1996), "Pitch detection based on prototype waveforms," proceedings of the ISSPA 96. Proceedings Main Symposium Proceedings of Fourth International Symposium on Signal Processing and its Applications, Gold Coast, Qld., Australia.

C. I. Duruöz (1997), "Synthesis of Transients in Guitar Sounds," proceedings of the International Computer Music Conference, Thessaloniki, Hellas.

A. Freed and R. Avizienis (2000), "A New Music Keyboard featuring Continuous Key-position Sensing and High-speed Communication Options," proceedings of the International Computer Music Conference, Berlin, Germany.

A. Freed, R. Avizienis, T. Suzuki, and D. Wessel (2000), "Scalable Connectivity Processor for Computer Music Performance Systems," proceedings of the International Computer Music Conference, Berlin, Germany.

S. Kartadinata (1996), "Repluck Detection for Guitars and String Instruments," CNMAT.

C. Patton (1992), "King of the Delta Blues: The Music of Charley Patton (CD)," : Yazoo.

L. S. Smith (1994), "Sound segmentation using onsets and offsets," *Journal of New Music Research*, vol. 23, num. 1, pp. 11-23.

G. Weinreich (1977), "Coupled piano strings," *Journal of the Acoustical Society of America*, vol. 62, num. 6, pp. 1474-84.

G. Weinreich (1979), "The coupled motions of piano strings," *Scientific American*, vol. 240, num. 1, pp. 94-102.