“Old” is the new “New”: a Fingerboard Case Study in Recrudescence as a NIME Development Strategy

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ABSTRACT

This paper addresses the problem that most electrophones and computer-based musical instruments are ephemera lasting long enough to signal academic and technical prowess. They rarely are used more than in a few musical performances. We offer a case study that suggests that longevity of use depends on stabilizing the interface and innovating the implementation to maintain the required stability of performance for players.

Keywords

Fingerboard controller, Best practices, Recrudescence, Organology, Unobtainium

1. INTRODUCTION

Of the dozens of interesting electrophones designed after the invention of the greatly-enabling vacuum tube, only two general class of devices and three specific devices achieved sufficient cultural uptake to last over a generation: amplified instruments, keyboard electrophones, the Theremin, Ondes Martenot and Trautonium [7, 8]. We focus on a key contingency of this long-term cultural uptake, the requirement of a stable interface that support the player’s investment in learning. We suggest that for instruments to be long lasting aa shift is required from innovation in the interface itself to innovations in the reliability and re-implementability of this interface.

2. HISTORICAL CONTEXT

Establishing causal relationships to explain the rise and fall in popularity of certain instruments and instrument types is notoriously difficult [2] and in fact the whole enterprise itself might be regarded as an artifact of a tired, old, pervasive obsession with triumphist, declinist, and progressivist tropes in history. We therefor eschew a teleological approach and look instead for correlations between the surviving instruments and contingencies that sustain their ontological status, i.e., we adopt a teleonomic attitude.

The lasting instruments of the 1930’s had both a virtuosic and charismatic promoter to signal their value and also promotional vehicles such as newsreels, international exhibitions and cultural institutions with significant composers to collaborate with. Importantly, the original inventors (and in some cases performers) were able to find ways to continue work on the instruments after the considerable disruptions of WWII.

In the 1950’s television served as a new opportunity for promotion as programming included new instruments and unusual compositions (such as those of John Cage), engaging audiences in a safe venue where they could encounter novel and disruptive technology and art.

The 1960’s provided both the challenges and disruptions of the transistor as they displaced vacuum tubes in most electronic devices and as consumers became impatient with the requirement to replace failing vacuum tubes.

We see in these contextual dynamics that the emergence of opportunities and disruptions required constant change against a background of declining energies and diffused interest of the original champions of the devices–a key factor in what Weber called charismatic authority.

The long-lived instruments embody ways their designers resolved a key dilemma we will examine in the rest of the paper that is reflected in the contradiction inherent in the bookend letters of NIME. In order for performers to learn how to be expressive with musical instruments, i.e. to instrumentalize them in performance, they need the instruments themselves to manifest years of stability. Concurrent with this requirement for stability the designer is under pressure to renew the instruments to maintain future customer interest and also because the constituent materials and technologies wear out and become unobtainium.

The successful strategy we see among instruments with cultural traction is a shift of the domain of innovation from the interface experience for the performer to the implementation of the instruments themselves in such a way as to maintain the defining properties of the instrument. This strategy is evident when we see how instrumental Bob Moog was in moving the Theremin and Trautonium into the transistor era and also when we realize that the majority of working Ondes Martenot’s are from the last production runs, a re-implementation with transistor circuitry.

3. PROPOSAL AND BENEFITS

It is too early to tell whether this nuanced innovation strategy that celebrates re-implementations will result in long-lasting instruments and controllers as it takes a generation at least to evaluate cultural uptake. However, we strongly signal this direction and invite the computer and electronic music instrument building communities to embrace and encourage re-implementations of older instruments with their various, interesting affordances. We invite the broader academic and music community to recognize such work as valuable and also novel.

4. OLD IS THE NEW NEW

4.1 Unity

This broader perspective of what constitutes “new” instruments can unite the NIME development community and communities of experts in older electrophones and acoustic musical instruments who publish in the journals of organizations such

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as AMIS and CIMCIM. These dialogs will result in a productive challenge to the progressivist rhetoric of much recent work. For example, it is often assumed that a digital interface is automatically better because digital technology is better than transistors that are in turn better than vacuum tubes. In fact, after 100 years, we still have a lot of difficulty achieving the pitch control precision of the early fingerboard instruments (Theremin Cello, Trautonium, Ondes Martenot) and the core technical issue has little to do with tired debates of analog vs. digital or the particular amplification device technology employed. As we will see the heart of this particular problem is materials engineering.

4.2 SKILL SHARING FOR LONGEVITY

Re-implementations and longitudinal comparative studies will result in better sharing of skills and technologies that will lead to integration of robustness and longevity into all controller and instrument projects including those with novel user interfaces.

5. BOWED FINGERBOARD CASE STUDY

The following case study chronicles work spanning the last ten years refining implementations of bowed fingerboard controllers. We humbly propose it as a model of how shifts in focus from interface innovation to implementation innovation might be documented. Along the way we include some “best practices” that we hope will increase the longevity and cultural uptake of the future instruments.

5.1 INVENTION DEMYSTIFIED

As with much invention, the tip of the long nose of innovation [1] that we present is neither a moment of divine inspiration nor the work of a rare genius on a good day but a simple repurposing to solve the following problem: While it is straightforward to find places on a cello to put new transducers that are easy to reach for the stopping hand, the bowing hand is more difficult to provide for. One approach, typified by the k-bow [3], is to equip the bow itself with sensors. In light of the high cost of this and the attachment performers have to their prior bow choices, we elected to add a wheel to the axle of an absolute-position rotary encoder attached to the endpin of a Jensen 6-string cello [1bis] (Figure 1).

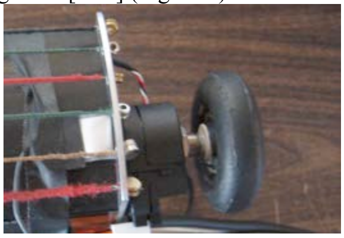

Figure 1. Bowable Encoder of Augmented Cello

The wooden toy car wheel proved to be too slippery to bow effectively so it was covered with gaffer’s tape that provided a rougher texture. The ease with which this wheel could be bowed suggested that bowed chordophone controllers could be built with rotating rods instead of strings.

In collaboration with Frances-Marie Uitti, we developed a 12-rod, stringless controller that can be played with two bows illustrated in the components of figures 2 and 3. The rods are symmetrically arranged around a central structural member as shown in Figure 2.

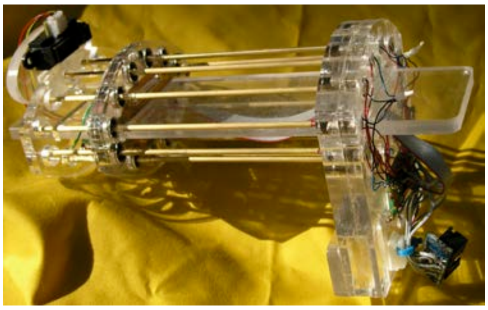

Figure 2. Rotating Rods (12)

The spacing of the rods was too tight to allow the use of off-the-shelf rotary encoders so the rods were coupled to the axles of small pager vibration motors. Operating as generators, the motor velocities can be readily measured by averaging the amount of current they produce. This left the challenges of sensing bow position and bow pressure. Position was measured using an IR proximity sensor. Bow pressure was sensed by surrounding a bearing with a sandwich of conductive and piezoresistive fabrics. These newly-available fabrics were a key enabler for this project because annular pressure sensors are not commercially available.

The fingerboard for this controller (Figure 3) was surprisingly challenging to develop.

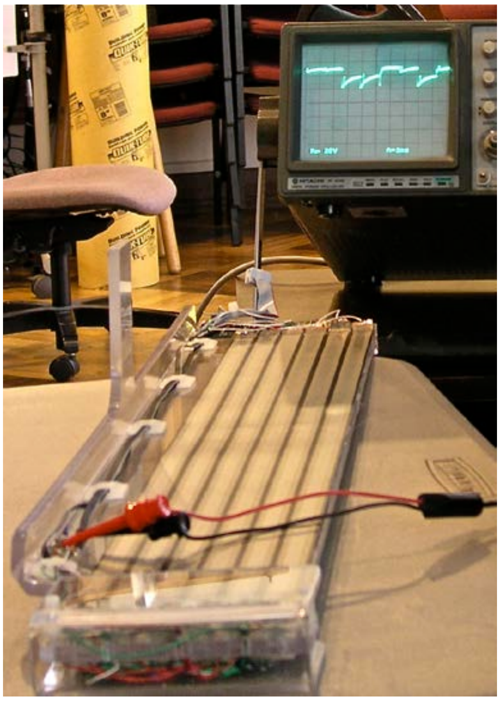

Figure 3. Fingerboard Array

The challenges result from linear position sensing strips being unavailable commercially at the required length. Interlink sensing strips are available but they are built to sense pressure not position. Noting that they contain the same components as position sensing strips, we developed a way to reliably add electrical connections to each end of the resistive polymer so that each of 12 strips could sense position in two separate places and a single composite pressure.

What we implemented was an example of “old” being the new “new” because collocated position and pressure sensing is the core innovation of the Trautonium, being itself a reimplementation of the same tangible interface of the earlier Hellertion of the 1920’s. For pressure-mediated sound level the

Hellertion coupled the bending of the conductive strip to cause a rapprochement of the secondary and primary windings of the transformer that coupled the main oscillator to the output amplifier. To provide a crisp switching action the conductive strip also controlled a contact point in a pot of mercury–an example of an implementation that is important to improve upon given what we now know of mercury toxicities.

5.2 PUTTING IT ALL TOGETHER

The primary design constraint we faced assembling the sensor components into a playable controller was that the result would be within the scope of comfortable gestures cellists. We also wanted the controller to be transportable as carry-on luggage for international plane flights. It therefor had to be built as a series of connectable components.

Figure 4 shows a rough early physical prototype held by a stand-in and built from laser cut acrylic to explore the mechanisms of component assembly and prepare for the opening design conversations with Frances-Marie Uitti.

Figure 4. Structural Prototype

Noting that this controller was going to be much lighter than a cello, we explored configuring the instrument to sit on the legs rather than the ground with the fit closer to a gamba than a cello. These base pieces are interchangeable so a base such as the one shown in Figure 5 can be used for familiarity to cellists.

Figure 5. Stringless Cello Body

The laser-engraved surface textures improve the grip of this “body” between the knees of the performer.

5.3 MEASURE NEVER: CUT OFTEN

In a deliberate inversion of the old maxim “measure twice cut once” the mechanical design of the controller components shown in this article was done without use of rulers, calipers or numerical measurements. This is just one of many strategies employed to avoid normative design practice wedded for hundreds of years to technologies of replication. Our goal is to achieve the best fit for a particular performer so the molds that the controller components are made from had to be from her body or in the case of Figure 5 an *objet trouvé* serving as a proxy. In this case it was a large plastic water jug that Frances Marie Uitti found to be the right size. The heated acrylic was formed by hand over this water bottle, just as the characteristic red roofing tiles of the Spanish-style building we were developing in were formed over the thighs of ceramic workers.

This “measure never: cut often” approach was readily supported by 2D CAD software and a laser cutter. The key to efficiently arriving at a viable controller with a small number of iterations is to refine as many variables as possible at each step. Nudging and scaling tools were used in the CAD program to incrementally refine. Very few components required more than four iterations. Each iteration benefited from knowledge of the actual fit which is essential with the laser cutting process because the conical light source and the particular melting properties of acrylic conspire to alter the actual part from its ideal form expressed in the CAD tool.

5.4 PRODUCTIVE FAILURE

Despite our best attempts to work the problems that arose, the prototype controller was not viable for professional performance and now serves to guide future developments. Although functional and comfortable, the performance of the sensor systems of the instrument was not consistent enough or inherently accurate enough for nuanced playing.

Struck by how much better the Ondes Martenot and Theremin Cello were in these respects, development shifted focus from a satisfactory interface design to innovation in the implementations–borrowing what we could by studying the earlier instruments.

The basic implementation scheme our antecedents adopted was to use materials and mechanical design that optimize for precision while accuracy was often deferred to the user by way of some adjustment scheme. This is the same strategy used in conventional lutherie where material choices allow for precision in the short term but their sensitivity to temperature, humidity and wear precludes achievement of accuracy without intervention (via tuning pegs, for example) of the player. One sees this at an extreme with the reeds of the oboe. They last a very short time but skilled hands can be make them with great precision and functionality.

It is difficult to achieve comparable precision with current engineering practice because additive processes such as printing are favored with low material volume and mass to enable large-scale manufacturing. Precision is easier to achieve with subtractive and forming processes with bulk materials. For the fingerboards of the 1930’s instruments subtractive and bulk forming can be seen in the use of strips and resistance wire.

5.5 WAYS FORWARD

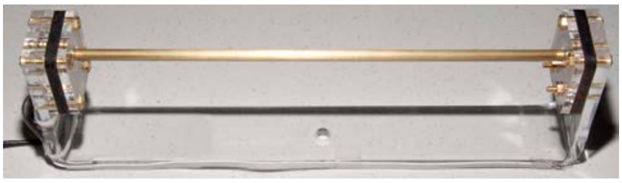

Figure 6. Monochord

To efficiently move forward developing best practices for greater controller precision, we focused on a simple monochord and careful improvements to every aspect of the engineering. One key enabling technology is the use of magnetic rotary integrated circuits sensors that can represent the orientation of a magnet with 12-bits of resolution. Figure 7 shows a large rod that spins on two skateboard bearings. Each bearing contains a pressure sensor. Rotational position is sensed at one end using a magnet and magnetometer integrated circuit.

Encouraged by the results from this prototype, we developed the controller in Figure 8 that is similar in scale to a large viola. It includes a high-resolution fingerboard. Interchangable base pieces allow this instrument to be played under the chin or on the legs like a gamba or on a thigh like the erhu.

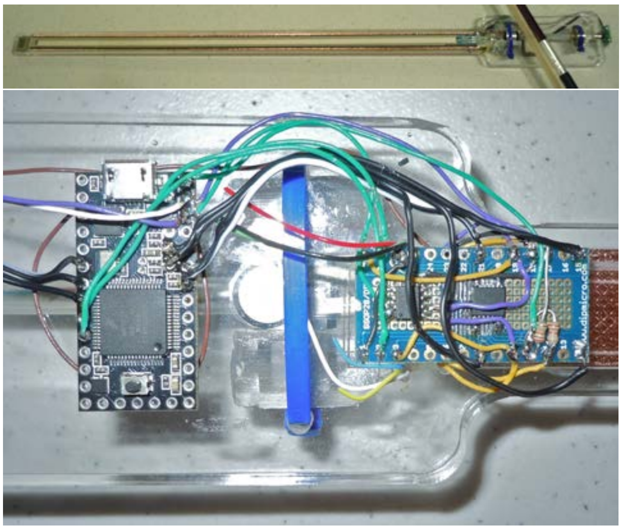

Figure 6. Precision Fingerboard Controller

This higher resolution was achieved with numerous improvements to the original stringless cello design. The single most important change was to abandon the 8-bit microcontroller of earlier prototypes and use the ARM-based 32-bit processor of the Teensy 3.0 board for the sensor processing. This particular microcontroller has 16-bit ADC and plenty of computational capability to implement calibration and machine learning algorithms to linearize the sensor data. The step from 10-bit to 12-bit or greater ADC performance requires careful analog circuit design and circuit layout–something that is hard to find in the DIY Arduino community, for example [5, 6]. The schematic of Figure 9 demonstrates the high-performance, analog front-end circuit.

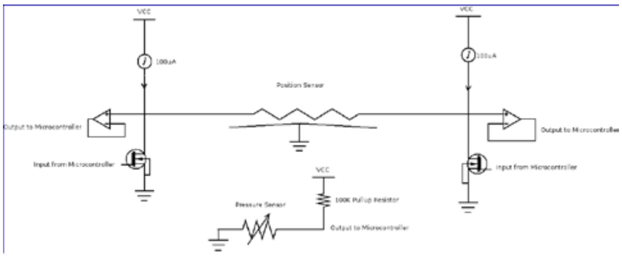

Figure 7 Analog Front-end

Here is a summary of design improvements and features that work together to achieve better than 12-bit position resolution and high repeatability:

Pull up resistors replaced by precision current reference ICs.

High impedance resistive strips (1Megohm) are replaced by lower impedance strips (20Kilohm) to lower noise.

Precision, low input offset op-amp buffers provide low impedance to the ADC multiplexer increasing precision and speed of conversion.

Low on-resistance, power mosfet current-steering switches allow for regular monitoring of the resistance of the full strip length when fingers aren't depressing it. This resistance is then used as the denominator to compute finger position as a ratio thereby compensating for temperature changes and aging of the strip.

The relatively high capacitance inherent in the mosfets provide a low pass filter that attenuates RF noise injection at the node.

All wires from the sensors are brought close to the analog circuit nodes to minimize noise pickup.

The stacked position strip and pressure strip sit on a grounded copper strip. The topmost sensor conductor is also grounded forming a shielding Faraday cage around the sensors.

All ADC conversions are isochronous, synchronized to a high precision crystal clock minimizing the impact of jitter-induced noise.

Conversion timing is carried as time-tags with the data in OSC facilitating correct gesture signal processing.

On-chip averaging of built-in ADC to filter noise.

On chip high-precision voltage reference is used for A/D conversions.

All digital control pins except those for USB are disabled during analog data acquisition to remove coupled noise sources.

Analog electronics is powered from the 3.3V analog supply and ground of the microcontroller.

As an indication of the resolution we can achieve with this careful practice we show in figure 10 that we were able to acquire data from a small vibrato gesture comparable in precision to that achieved with a high-quality, fabric multitouch system [4].

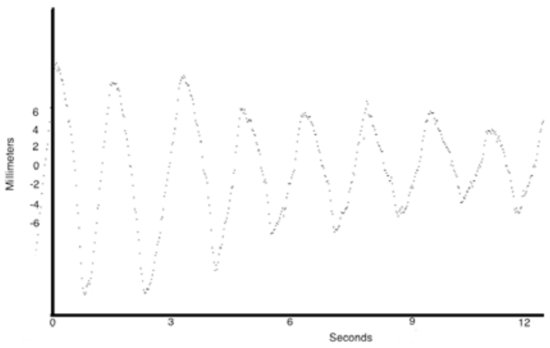

Figure 8. Vibrato Gesture

6. Discussion

We have noted that there is a tradeoff between precision and cost due to various popular manufacturing processes and the high cost of labor-intensive approaches such as winding resistance wire. The new rapid prototyping and additive manufacturing approaches that are becoming more affordable will change this tradeoff introducing new opportunities for precise and affordable instrument building. We note, for example, that 3D printers can be configured to print conductive material and therefor may offer a way to produce a high stability resistive strip sensor [2].

It is often argued that skill and design sharing through the Internet and DIY communities are simply making the academic discourse on new instrument building irrelevant. The velocity of knowledge sharing by this route will always exceed that of traditional peer-reviewed publishing. However, a moderate restructuring of academic publication practice will allow for a productive synergy between academic and DIY work. To proceed we will have to challenge and change subtle aspects of publishing practice For example, consider the following policy from the Computer Music Journal:

> *"**Algorithms.** The Journal publishes algorithms but not program listings. Algorithms should be described in a well-known programming language and thoroughly commented (i.e., more English than program)."*

Although well intentioned, the result of this is that very few algorithms are published at all and the CMJ is not a reference source of best practices for computer music programming. On the other hand the DIY community has produced enormous amounts of example code but has little peer-reviewed curation favoring instead the emergence of a first-fit "do-ocracy"

Another subtle example is the use of two-column, 9pt text so common in academic publishing. Again this is well intentioned: it is to allow authors to say a lot in the limited print space for 4-8 pages. This is no longer necessary as proceedings are so rarely printed. This format, optimized for printed text, makes it impossible to include long example of useful code, PD or Max/MSP patches or circuit diagrams. It is also hard to include reasonable pictures of the instruments themselves. Deferring to web links for this material isn't an adequate solution because it disassociates writing exactly from that material we suggest can benefit most from peer review for practitioners.

The brief case study we have presented and the underlying design principles adduce our vision of new publishing opportunities and a route to instrument innovation with greater cultural relevance and uptake.

7. ACKNOWLEDGMENTS

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