On making physical the control of audio plugins: the case of the Retrologue Hardware Synthesizer

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Figure 1: Physical control of the Retrologue plugin via the Retrologue Hardware Synth prototype.

ABSTRACT

This paper reports the development of a prototype of smart musical instrument that uses a virtual analog audio plugin in conjunction with a dedicated tangible interface and a platform for embedded audio. The adopted design approach started from an analog synthesizer, passed from its digital emulation, and returned to the analog domain via the real-time, physical control of the digital synthesizer. The prototype can be considered as an instance of a class of musical devices that allow one to give physical form to the control of virtual analog software. We present an analysis of online sources that were retrieved following the release of the prototype at an international music trade show. Overall, results preliminary validate the concept underlying the development of the prototype and reveal its potential for both digital musical instruments development and use. Benefits of the proposed class of musical devices include a higher degree of control intimacy of a plugin compared to its use with conventional interfaces such as mice and screens of desktop computers, as well as the use of audio plugins in ubiquitous musical activities.

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CCS CONCEPTS

• **Computer systems organization → Real-time operating systems**; *Embedded software*; • **Human-centered computing →** Sound-based input / output.

KEYWORDS

Internet of Musical Things, Smart Musical Instruments, Embedded Audio, Virtual Analog

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1 INTRODUCTION

Digitization refers to the conversion of various types of information (e.g., text, pictures, or sound) into a digital form that can be read and processed by a computer. The trend of turning everything into a digital form has also impacted the musical domain, and in particular that of devices used in the production of electronic music [29], an endeavor that is commonly referred to as "virtual analog". Examples within this category include virtual analog synthesizers [22], virtual analog filters [30], virtual musical instruments [19, 32], reverb emulations [31], and guitar amplifier models [21].

All these categories of software have in common the simulation in the digital domain of a counterpart in the analog domain, via the use of digital signal processing techniques. For instance, virtual musical instruments simulate the functioning and behavior of real acoustic or electric musical instruments with a focus on the sonic aspects of the emulation (e.g., sounds of percussive instruments rendered by physical modeling techniques [5]). Analogously, virtual analog synthesizers mimic the circuitry found in analog synthesizers, typically simulating the effects of the sound synthesis technique called subtractive synthesis on which such analog synthesizers are often based.

To date, virtual analog still represents an active area of research in both academy and industry with various papers presented each year at the International Conference on Digital Audio Effects (see e.g., [7]) and related venues. Moreover, each year new products based on virtual analog enter in the market following a solid demand from musicians. Currently, most of virtual analog software is released in the form of plugins that can be used by digital audio workstations (DAWs) running on desktop computers, such as Logic, Cubase, or Ardour to name a few. Various kinds of plugins formats have been created, including Steinberg's Virtual Studio Technology (VST)[1], Propellerheads' Rack Extensions[2], and the Linux Audio Developer's Simple Plugin API version 2 (LV2)[3].

Digital signal processing allows one to avoid some of the downsides of analog electronics, such as the dependency of tuning on temperature-related conditions found for analog synthesizers. However, virtual analog software is typically conceived for use in conjunction with desktop computers, where the control of the software parameters is relegated to input devices such as mice, computer keyboards, or other devices such as musical keyboards that needs to be plugged to the desktop computer. These aspects limit the use of such software in more ubiquitous musical activities, such as those fostered by the so-called Ubiquitous Music field [10, 11]. Specifically, Ubiquitous Music refers to music or musical activities that are supported by ubiquitous computing concepts and technology [24, 33]. It has been defined as *"ubiquitous systems of human agents and material resources that afford musical activities through creativity support tools"* [11].

Recent technological developments in the domain of embedded audio, i.e., embedded systems dedicated to digital audio processing (see e.g., the Bela board [14]), have led to the possibility of using a variety of audio plugins on single board computers such as the RaspberryPi or the Beaglebone. This has opened novel opportunities to create hardware devices for ubiquitous music purposes, such as digital musical instruments [16], which employ audio plugins as the core technology for digital audio processing.

This paper reports the development of a prototype of smart musical instrument that uses a virtual analog audio plugin in conjunction with a dedicated tangible user interface [8] and a platform for embedded audio. The adopted design approach started from an analog synthesizer, passed from its digital emulation, and returned to the analog domain via the real-time, physical control of the digital synthesizer. The prototype can be considered as an instance of a specific class of musical devices that allow one to give physical form to the control of virtual analog software. We present the results of an evaluation study conducted via the technique of online observations, which aimed at assessing our design concept. Finally, we discuss the opportunities opened for musical instruments designs.

[1]https://www.steinberg.net
[2]https://www.reasonstudios.com/
[3]https://www.ladspa.org/

2 BACKGROUND

2.1 Benefits and downsides of desktop virtual analog software

Considering a technical perspective, virtual analog software presents various benefits compared to their analog counterparts. Firstly, analog synthesizers may suffer from temperature-dependent tuning problems. On the contrary, in digital synthesizers the oscillator pitch is maintained by a digital clock, and the digital hardware is typically less susceptible to temperature changes. This confers more reliability to virtual analog synthesizers than their analog counterparts. Secondly, small differences in the sound may occur between two analog synthesizers of the same model and of a same manufacturer due to the minimal variations that inevitably are present between analog circuitries. Conversely, digital synthesizer have always the same sound, thus providing a more "standardized" timbre.

Thirdly, whereas analog synthesizers require an oscillator circuit for each voice of polyphony, virtual analog synthesizers are exempt from this issue since they can produce as many polyphonic voices as the memory and CPU on which they run can handle. Moreover, virtual analog software allows one to explore a wider range of sonic possibilities, including sounds that could not be achieved by an analog synthesizer due to physical constraints of its internal circuitry. In addition, virtual analog software provides patch storage capabilities as well as MIDI support, which are not available on many analog instruments. Along the same lines, digital devices running virtual analog software can relatively easily be empowered with wireless connectivity. This enables the control of the virtual software parameters from external devices, an aspect that falls in the endeavors of the so-called Internet of Musical Things [27].

On the other hand, digital signal processing has limits and undesirable side-effects (e.g., quantization noise, aliasing), and research has devised a number of solutions to emulate the analog world in a realistic way (e.g., augmenting the quantization resolution, oversampling, antialiasing techniques) [20, 28, 30]. However, besides technical drawbacks related to the actual rendering of an analog device into the digital realm, downsides for virtual analog software may reside in their real-time control. Typically, this software is released as a desktop application and is controlled by standard input devices such as mice and computer keyboards. Notes can be also injected in the software by means of MIDI keyboards attached to the desktop computer, while different kinds of controllers plugged into the computer can be used to control the software parameters via automations. Nevertheless, the need of using a desktop computer as well as a multitude of devices connected to it to control a software limit the ubiquitous use of such software.

Furthermore, the use of generic input devices such as the mouse and the computer keyboard strongly constrain the "control intimacy" while using virtual analog software, in both sound design and performance scenarios. Control intimacy, is a term that was first introduced by Moore in [17]. It relates to a performer's perceived correspondence between his/her psychophysiological capabilities when controlling the instrument and the resulting response of the instrument. Building on Moore's notion of control intimacy, Wessel and Wright proposed that a high degree of control intimacy fosters the continuous development of performers' skills on an instrument as well as his/her personal performative style. On the contrary, a low level of control intimacy is found for devices that limit the expressive possibilities of a performer, as the richness and nuance of a performer's gesture is poorly translated into the instrument musical output [34]. Differently from their digital synthesizers controlled by typical desktop input devices, analog synthesizers have a much higher degree of control intimacy, as they accommodate a wider variety of performance gestures and offer a more direct tactile feedback from the interaction of the hands with the components of their control interface, such as knobs, faders or buttons.

Another project worth mentioning is Mod Duo by Mod Devices[4]. The Mod Duo is a stereo device that can accept line or mic signals, and which can host both effect and instrument plug-ins. In particular, Mod Duo can run multiple chains of plug-ins to create virtual pedalboards. The device runs Linux LV2 plug-ins, as well as plug-ins programmed in MaxMSP, Pure Data or Faust.

2.2 Embedded audio

One of the strands of research in digital musical instruments design is the one that has prioritized self-containedness, leveraging platforms for embedded audio that are typically open source hardware and software projects (see e.g., [9, 12, 13]. In the past decade various Linux-based platforms for creating self-contained musical instruments [1] have been developed, which mainly target the makers community [18]. Meneses et al. [15] provide a recent comparative study in this space.

A prominent example of platforms used for creating self-contained digital musical instruments is Satellite CCRMA [2, 3], which is based on Raspberry Pi or BeagleBoard xM single-board computers connected via a serial port to an Arduino microcontroller, and uses open source software for generating audio. Other similar platforms targeting the makers community are Axoloti[5] and Prynth [6]. Currently, one of the most advanced systems in this space is represented by Bela [14], a platform based on the BeagleBone Black single-board computer, which is extended with a custom expansion board for audio and sensors input/output and which uses the Xenomai real-time kernel extension to achieve processing latencies below 1 ms.

Another open source project, targeting both the maker community and developers of professional audio equipment, is Elk Audio OS. This is a recent operating system based on Linux, which is specifically conceived for embedded audio applications. It has been developed by the Elk company[6] (former MIND Music Labs). It was released on the market in 2018 and as an open source platform for the Raspberry Pi in late 2019. Like Bela, Elk uses the Xenomai real-time kernel extensions to achieve latencies below 1 millisecond, which makes it suitable for the most demanding of low-latency audio tasks. It is highly optimized not only for low-latency, but also for high-performance audio processing as well as for handling wireless connectivity. This makes it an enabler for Internet of Musical Things applications [27], such as for instance the class of the so-called smart musical instruments [25] (see e.g., the Sensus Smart Guitar [26]). Notably, Elk is capable of running VST and Rack Extensions plugins on Intel and ARM CPUs embedded in dedicated hardware systems. Furthermore, it offers efficient development tools that allow developers to easily port to embedded systems the code written for desktop applications. In 2019, Elk was officially incorporated into the VST Software Development Kit by Steinberg.

[4]https://www.moddevices.com/
[5]http://www.axoloti.com/
[6]https://www.elk.audio

3 NEW OPPORTUNITIES FOR MAKING PHYSICAL THE CONTROL OF AUDIO PLUGINS

Section 2.2 reviewed the state-of-the-art for creating self-contained instruments thanks to various platforms for embedded audio. From the surveyed literature, it emerges that at present Elk Audio OS appears to be the most technically advanced open source platforms for embedded audio. In particular, its features allow plugin developers to turn their software into dedicated ultra low-latency hardware devices. Platforms with these characteristics provide novel opportunities for musical devices design. This includes the creation of self-contained digital musical instruments that can give physical form to the control of audio plugins, including the virtual analog ones.

This technical advancement has the potential to merge in a unique solution the benefits of virtual analog synthesizers listed in Section 2.1 with those of analog synthesizers related to the real-time control. This allows one to achieve a higher level of control intimacy while interacting with the virtual analog synthesizer compared to the case in which the plugin hosted on a desktop DAW is controlled using a mouse and computer keyboard. In addition, virtual analog synthesizers running on an embedded platform can be constructed around a smaller chassis compared to their analog counterparts, as well as dedicated hardware avoids the situated use of desktop computers and of multiple input devices attached to it. This enables a ubiquitous use of the virtual analog software, in accordance with the tenets of the Ubiquitous Music field. Furthermore, the use of Elk allows for the creation of connected devices dedicated to Internet of Musical Things applications.

The next section describes a prototype that aims at giving life to the concept of making physical the control of audio plugins thanks to a self-contained musical instrument leveraging a platform for embedded audio able to support plugins. The adopted design approach started from an analog synthesizer, passed from its digital emulation, and returned to the analog domain via the real-time control of the digital synthesizer via a dedicated tangible interface.

4 THE PROTOTYPE

A proof of concept prototype was developed to implement the idea of creating a self-contained musical instrument around an audio plugin. Such a prototype, named Retrologue Hardware Synth, resulted from a collaboration between the companies Elk and Steinberg. It is based on two components: the Retrologue virtual analog plugin and a dedicated chassis.

Retrologue[7] is a software developed by Steinberg that emulates classic analog synthesizers. It has three oscillators with waveform mixing, a multimode filter, various envelopes, 4 low-frequency

[7]https://new.steinberg.net/retrologue/

oscillators (LFOs) and a modulation matrix. It is equipped with various effects and polyphony. Figure 2 illustrates a screenshot of the Retrologue plugin.

Figure 2: A screenshot of the Retrologue 2 VST plugin by Steinberg.

The plugin is hosted within a self-contained hardware device covered in hands-on performance controls, see Figure 3. It contains a powered-by-Elk embedded system (precisely an Aaeon Upcore[8] with a dedicated shield for audio processing developed by Elk) on which the Retrologue plugin runs, as well as all the electronics that connect the controls in the panel (faders, knobs, buttons) to the embedded system. The panel encompasses 3 oscillators, a mixer (where it is possible to add a sub-oscillator and noise), as well as filters and VCA, each with its own envelope. In addition an LFO is present, which can be routed for different purposes.

The prototype has full MIDI support which allows for the input of notes via a keyboard. In addition, the instrument is empowered with Wi-Fi IEEE 802.11ac connectivity, which enables a range of Internet of Musical Things applications (including e.g., the configuration of the plugins parameters missing in the physical interface via a dedicated app running on smartphones). Taken together, these features make the Retrologue Hardware Synth an instance of the family of smart musical instruments proposed in [25].

The prototype of the Retrologue Hardware Synth debuted at the Superbooth 2019 in Berlin, an international music trade show for analog and digital synthesizer as well as audio equipment at large. A video of the prototype in action is available at https://youtu.be/uiTrr6Tdfxs.

5 CONCEPT EVALUATION

We evaluate our design concept by means of online observations, a technique methodologically rooted in the human-computer interaction field [23]. When presented at the Superbooth 2019 music trade show, the prototype received a great media coverage and the attention of specialized websites and forums. A total of 9 different videos (with comments associated to them, e.g., on YouTube), 49 webpages, and 6 forums topics/comments to blog posts were retrieved and analyzed. These online sources were in 6 different languages: Italian, English, Spanish, German, Swedish, French.

Figure 3: A picture of the Retrologue Hardware Synth prototype developed by Elk in partnership with Steinberg.

Twenty of the websites simply reported or rephrased the content that was available on the press release page of Elk's website[9] about the prototype showcase at Superbooth 2019[10]. The vast majority of the other sources reported positive comments on the prototype and/or the concept underlying, while very few comments were less appreciative.

The data gathered from each online source was analyzed by means of an inductive thematic analysis technique [4]. We generated codes from the results of each technique and the codes were further organized into themes that reflected patterns. The analysis was neither conducted on market aspects nor on sound quality aspects of the prototype, but only on the concept (as this is the focus of the present study). The following themes were identified:

Interest for the concept. 3 videos, 9 web pages, and comments on 2 forums clearly expressed enthusiasm and interest for the novelty of the concept brought by the Retrologue Hardware Synth (e.g., *"Very interesting development for soft synths"*; *"[The prototype] provides controllers for a plugin already existing, I find it very interesting."*; *"It's a synthesizer... in hardware form... that runs its own software as a plugin, and it's not just a controller, it's a controller for the plugin that lives inside of it."*).

Physicality of the interaction. 3 comments in forums and 11 webpages specifically referred to the tangibility aspect of the concept encompassed in the Retrologue Hardware Synth (e.g., *"It is just having my favorite plugin in hardware and being able to have hands on experience with it. It is feels so organic, it feels like playing an analog synth."*; *"I've been wanting a controller for my VSTs that feels like a real synth instead of a cheap plastic box. Quite interested here."*). Nevertheless, the word "physical" was utilized rather than the word "tangible" that is a term more utilized in the human-computer interaction academic community (e.g., *"As a proof of concept, the two companies have managed to get Steinberg's well regarded Retrologue 2 virtual instrument running in a bespoke*

[8] https://www.aaeon.com/en/p/iot-gateway-maker-boards-up-core

[9] https://www.mindmusiclabs.com/introducing-the-powered-by-elk-retrologue-2-desktop-prototype/

[10] https://elk.audio/retrologue-synth-desktop-synth/

desktop-format synth, making the dream of the "physical plugin" an impressive reality.").

Technological potential. Especially on websites and forums more related to software development topics, various themes were identified about the potential of the Elk technology as an enabler for various hardware devices running existing plugins (e.g., *"VST companies can license Elk and use it to make hardware devices of any one of their VSTs, that's the real news here."*; *"What I see is the ability for softsynth developers to easily get into the hardware market. They just need to design a case with the controls they specifically need. The OS is done by Elk and the synth is supposedly already done in this case."*).

Future developments. One of the most recurring comments found on websites relates to the future of the class of musical devices created around a certain plugin. 13 web pages wondered whether the Retrologue Hardware Synth is just the first of a series of plugins-powered devices, and whether other classic plugins will be turned into hardware synthesizers. Other comments expressed a wishlist for making tangible other plugins (e.g., *"I wish they would put the GSI VB3 organ into an affordable enclosure."*; *"They should do this for Diva or Sylenth1."*; *"More plugins please, and not just for software emulations of classic synths."*). Other sources showed curiosity for the potential avenues of the concept (e.g., *"I would be curious to see the physical controls for a plugin ways more complex such as Serum"*).

Wireless connectivity. The possibility of making the instrument communicate wirelessly with other devices such as a desktop computer was a feature very appreciated by some commenters in 2 videos and 2 forums. In particular, musicians found useful the possibility of configuring the instrument with parameters created on a desktop pc, as well as vice versa (e.g., *"You can create presets on the computer and then port them on the hardware and vice versa, this is a very cool thing"*; *"It's powerful, you can share patches between a computer and a hardware version."*).

Screen-based interactions. Few comments were made to the possibility of adding to the prototype a visual display, which even caused some light diatribes between members of some forums. Whereas some commenters were in favor of adding a screen either directly in the prototype or as a connected device (such as a smartphone or a tablet), other commenters deemed it pointless to do so as they preferred the physicality of the interface, like when interacting with a true analog synthesizer.

Less appreciation Not everybody welcomed with enthusiasm the concept. However, the less appreciative comments were only a very marginal part of the whole set of comments (e.g., *"Totally disappointed..in the first instance I was thinking an analog hardware version of Retrologue 2 with analogue circuits..this is just sort of Roland boutique with dsp inside...Why? If the sound is the same I just bring my laptop."*). Nevertheless, such commenters appear to not consider the actual interaction afforded by the new concept embodied in the developed prototype, but exclusively the sound produced by the instrument.

6 DISCUSSION AND CONCLUSION

This paper presented a prototype of a self-contained digital musical instrument that was built around an audio plugin. A design approach was adopted that started from an analog synthesizer, passed from its digital emulation, and returned to the analog domain via the real-time control of the digital synthesizer via a dedicated tangible interface. The prototype leveraged the Elk Audio OS, an operating system that offers the potential for software developers to turn their plugins into hardware. This translates in the fact that audio plugins originally conceived for a desktop use become available on embedded devices for a more ubiquitous use, thus enabling ubiquitous music activities [10, 11].

This technological advancement opens novel opportunities for digital musical instruments design, as it allows plugin developers (coding for e.g., the VST and Rack Extensions formats) to make hardware versions of their instruments and effects. Potentially, any plugin could be hosted within a self-contained hardware device covered in hands-on performance controls. Currently, other prototypes based on the proposed design concept have been built by the Elk company. A first example is an Eurorack synthesizer controlling Rack Extension plugins, which has been presented at the NAMM Show in 2019. A more complex instrument which involves the use of audio plugins on a hardware platform is the Sensus Smart Guitar [26].

The proposed concept was preliminary evaluated by means of the analysis of online material that was originated following the presentation of the prototype at an international trade show. From the thematic analysis of the online material, no theme related to the portability and ubiquitous aspects of digital musical instruments built around an audio plugin clearly emerged, nor the enabled opportunities for development and use of ubiquitous digital musical instruments. These, however, represent important benefits for musicians that are enabled by the proposed design.

Notably, in some contexts such as sound design activities, a more detailed visual representation of the status of the plugin may be useful (e.g., the dynamic graphical representation of the shape of a filter). Nevertheless, the possibility of adding a screen-based control (thanks to a connected smartphone or tablet) to a hardware specifically dedicated to a plugin allows one to extend the control possibilities offered by the tangible interface while keeping ubiquitous the instrument. A feature that was particularly appreciated is the possibility of sharing presets between a tangible plugin and the corresponding audio plugin running on a desktop computer. Such a feature usefully allows a musician to create a preset in two different ways and re-use it onto different media. It is worth noticing that this is an example of novel interactions between musicians and their machines afforded by the emerging class of smart musical instruments [25].

The interaction aspects of the concept were the ones that received more attention. As a matter of fact, the tangibility of a dedicated hardware interface for controlling an audio plugin enables a higher degree of control intimacy [17] compared to the use of standard screen displays and mice for desktop computers (which is in agreement with the tenets of the tangible user interfaces paradigm [8]). Moreover, the attention about future developments of the concept demonstrates an interest from a part of the electronic musicians and music technology communities towards this kind of technology and the possibilities enabled by it.

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