

# Augmenting the iPad: the BladeAxe

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## ABSTRACT

In this paper, we present the BLADEAXE: an *iPad*-based musical instrument leveraging the concepts of “augmented mobile device” and “hybrid physical model controller.” By being almost fully standalone, it can be used easily on stage in the frame of a live performance by simply plugging it to a traditional guitar amplifier or to any sound system. Its acoustical plucking system provides the performer with an extended expressive potential compared to a standard controller.

After presenting an intermediate version of the BLADEAXE, we’ll describe our final design. We will also introduce a similar instrument: the PLATEAXE.

## Author Keywords

Novel musical instruments, Novel controllers and interfaces for musical expression, Mobile music technology and performance paradigms, Embedded musical instruments and embedded sound art installations

## ACM Classification

H.5.5 [Information Interfaces and Presentation] Sound and Music Computing, H.5.2 [Information Interfaces and Presentation] User Interfaces—Graphical user interfaces (GUI), J.5 [Arts and Humanities] Music.

## 1. INTRODUCTION

While physical modeling of musical instruments has been an active field of research since the beginning of the 1970s [7], the use of physical-model-based instruments in real-time became seriously pursued only at the end of the 1980s with the discovery of the waveguide synthesis technique [21]. Thanks to its efficiency and simplicity and by combining forces with modal synthesis [1], dozens of musical instruments were modeled by the middle of the 1990s [5, 17] and the electronic music community was seeing it as “the next big thing” [16]. Indeed, unlike other sound synthesis techniques, the expressive potential of physical models seemed almost limitless. While most commercial products focused on modeling existing acoustic musical instruments, researchers in computer music saw it as an opportunity to quickly prototype and create novel instruments that would often transcend the laws of physics [4, 10].

However, one of the main challenges with waveguide-based physical models is to control them in a coherent and expressive way [23]. Unlike instruments using traditional sampling techniques where the expressivity is embedded (or not) in the sample, with physical models expressivity has to come from the different parameters controlling the instrument and is therefore still the performer’s responsibility. While this is not a big problem for instruments that don’t have a lot of continuous parameters, such as the piano, it is a major issue for instruments needing constant parameter adjustments (such as wind instruments). For live performances, this problem has been partially solved by creating interfaces providing more continuous control to the performer, such as the position and pressure sensitivity of the *ROLI Seaboard*<sup>1</sup> or the breath sensor on the *Yamaha VL1* (just to mention a few). However, things are more complicated when the performer is “virtual” [11].

In a previous publication [12], we introduced the BLADEAXE (see Figure 1) – a “hybrid controller” for guitar (and more generally plucked string instrument) physical models. This instrument leverages the idea that a great part of the expressivity translated from performer to instrument is often embedded in the excitation used to drive it [15, 14, 2, 3, 18, 24]. Indeed the strings and the body of the BLADEAXE belong to the virtual world while the surface of the strings is “materialized” through small plastic (polycarbonate) plates (the “blades”) that can be used to drive the virtual strings. Those blades were made to have the same elasticity and texture as real guitar strings. A piezo glued to each blade picks up vibrations that are then digitized, preprocessed, and fed directly into the digital waveguide representing the string (as detailed in [12]).

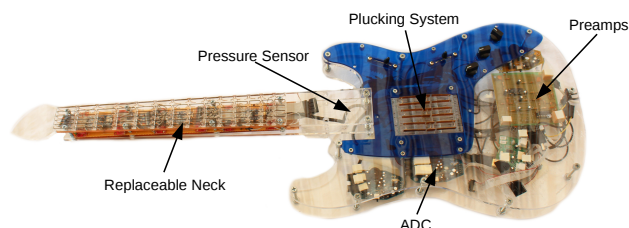


Figure 1: The first version of the BladeAxe.

The plucking system of the BLADEAXE provides an extended expressive potential to the performer by using acoustic excitations to drive virtual strings. Indeed, even the acoustical properties of the materials used to pluck the strings (skin, plastic, wood, etc.) are captured and impact the resulting sound. The excitation signal also naturally embeds the pluck position along the edge of the blade: for

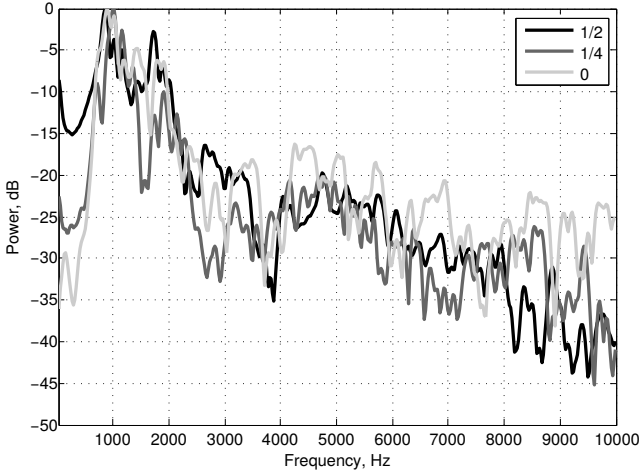
<sup>1</sup><https://www.rolid.com/> Accessed: 2016-01-18.



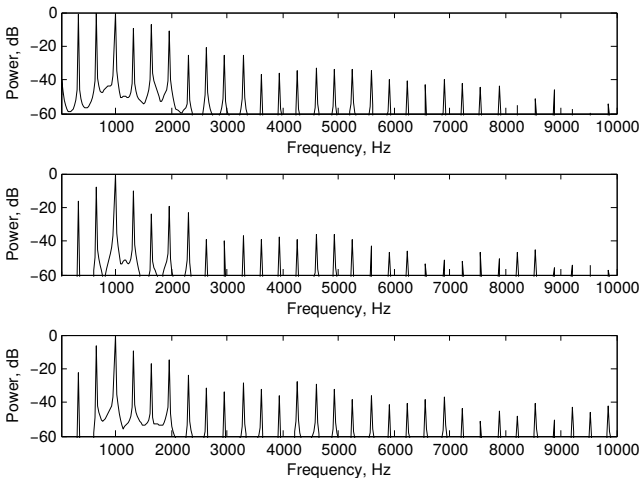
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NIME’16, July 11-15, 2016, Griffith University, Brisbane, Australia.

example, Figure 2 shows more energy below 1KHz and less energy above 4KHz when one of the blade is plucked at the middle rather than at one end. The pluck position uniformly affects the spectra of the virtual strings, for example the relative amplitude of the fundamental (typically below 1KHz) versus the higher harmonics, as shown in Figure 3: the virtual strings sound like they are plucked at different positions.



**Figure 2: Frequency responses of one of the blades when plucked at different locations with a pick where 0 is the bottom of the blade (towards the bridge) and 1/2 the middle.**



**Figure 3: Frequency responses of a virtual string when excited by the signals from Figure 2 (1/2, 1/4 and 0 from top to bottom).**

In this paper, we present the final version of the BLADEAXE<sup>2</sup>. It leverages the concept of “augmented mobile device” and it is quite different from the first version of this instrument introduced in [12]. Its design was greatly simplified by using an *iPad* both as a controller and to implement the virtual part of the instrument. This enabled us to make this instrument fully standalone reinforcing its “physical and virtual coherence.” After presenting an intermediate version of the

<sup>2</sup>Demo and concert videos featuring the BLADEAXE can be found here: <https://ccrma.stanford.edu/~rmichon/bladeaxe/> Accessed: 2016-01-18.

BLADEAXE, we’ll describe our final design. We will also introduce a similar instrument: the PLATEAXE.

## 2. AUGMENTING THE IPAD

Mobile platforms have been used a lot during the past ten years as musical instruments [8, 22]. They provide a fully self-contained/standalone environment with built-in speakers, various sensors (touch screen, accelerometer, etc.), and processing power capable of computing complex DSP algorithms in real-time. While a programmer or instrument designer might be limited by the sensor technologies available on such devices, they can be easily upgraded/augmented by mounting more sensors or elements on them. Doing so puts mobile devices at the heart of the musical instrument, implementing both its digital elements and some of its physical controllers (sensors). This section shows how we used this approach to make an intermediate version of the BLADEAXE where an *iPad* greatly simplifies the design of this instrument by implementing the idea of an “*iPad* augmented as a guitar”.

As we wanted to keep the same plucking system as the first version, we used the *iPad* as the neck of the guitar (see Figure 4). This implied major design modifications and also a totally different approach to the way this instrument was controlled. Indeed, while the various necks presented in [12] prioritized guitar playing skills transfer, this new version of the BLADEAXE cannot be controlled in the same way as a traditional guitar because of the shape of the touch screen. We also mounted an acrylic plate with laser engraved textures to the front face of the BLADEAXE, with its own attached piezo disc, allowing the performer to drive the virtual strings through a variety of interactions. Each texture creates a different sound excitation and implies a specific gesture: rubbing, scratching, tapping, etc. (see Figure 7).

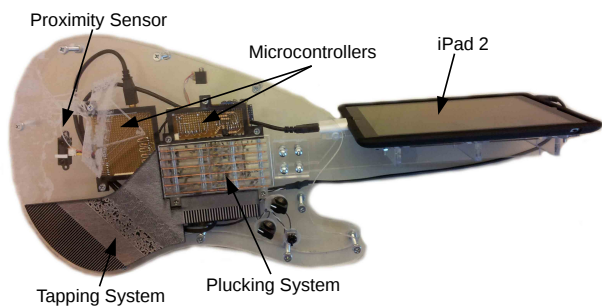
We wanted this instrument to be fully standalone and self-powered. Running the guitar physical model on the *iPad* forced us to do a series of optimizations detailed in the next section.

The most technically challenging problem that we had to solve with this instrument was to find a way to send the seven independent audio channels of the plucking system (the six blades plus the textured plate) to the *iPad*. We could have used a custom ADC (Analog to Digital Converter) just like we did for the first version of the BLADEAXE (see [12]), but this would have required the use of an external power supply such as a battery, greatly complicating the design of the instrument. Thus in order to use the built-in stereo ADC of the *iPad*, we had to find a way to differentiate the six blades; we used the capacitive touch sensors of the plucking system (see [12]) to detect which blade was plucked to route the excitation to the corresponding virtual string (see Figure 5). While this system worked fine if the performer was playing slow, it was hard to control in the frame of a piece involving fast playing.

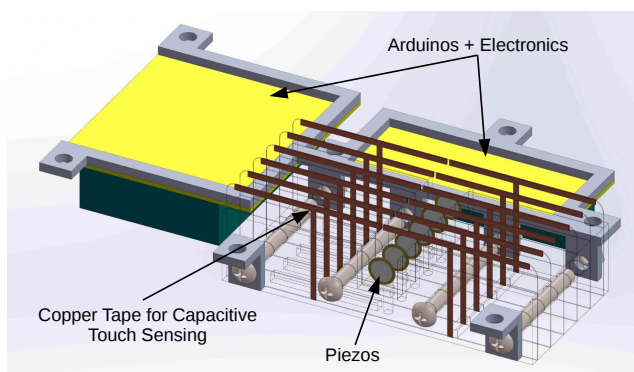
Another challenge was to find a way to connect the *Arduino* retrieving the touch sensing data from the plucking system to the *iPad*. Indeed, *iOS* devices let other devices connect to them only if they are approved by *Apple*. There are a couple of exceptions to that including MIDI controllers. We used Dimitri Diakopoulos’ work [6] as a basis to replace the serial USB driver of the *Arduino* with a MIDI USB driver making it usable with the *iPad*. Indeed, while a series of microcontrollers such as the *Teensy*<sup>3</sup> now provide built-in MIDI support, they didn’t exist when this version of the BLADEAXE was built. A proximity sensor was also

<sup>3</sup><https://www.pjrc.com/teensy/> Accessed: 2016-01-18.

embedded in the body of the BLADEAXE (see Figure 4) to control some of the effects applied to the model such as a *wah pedal*.



**Figure 4:** Intermediate version of the BladeAxe using an *iPad*.



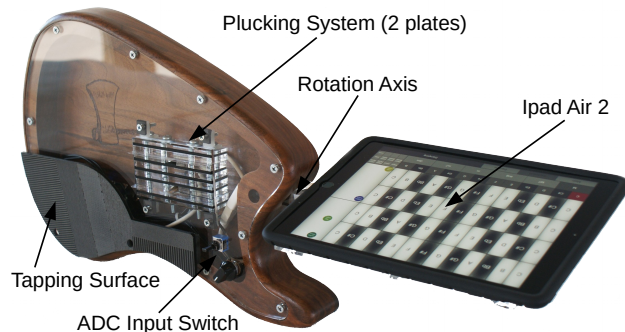
**Figure 5:** Plucking system of the intermediate version of the BladeAxe presented in Figure 4.

### 3. FINAL VERSION

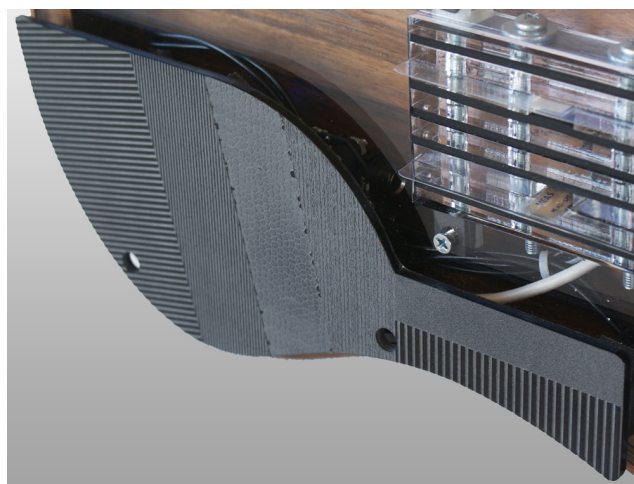
The final version of the BLADEAXE can be seen as a simplified version of the instrument presented in the previous section. The way the performer interacts with it was totally rethought and the number of blades was reduced from six to two (see Figure 6) allowing us to use a simple USB stereo ADC/DAC. We didn't use the built-in ADC/DAC of the *iPad* since it only has a mono input. The redesigned tapping/scratching surface hides the ADC/DAC. A switch mounted on the front face of the instrument makes it possible to route the signal from the two blades of the plucking system or from the tapping surface to any of the two input channels of the ADC. The USB ADC/DAC is directly connected to the *iPad* through the lightning connector since there is no microcontroller in this version of the BLADEAXE. The chestnut wood body of the instrument was CNC machined and laser engraved (see Figure 6). The built-in *iPad* sleeve is mounted on a rotating axis in order for the performer to be able to adjust its inclination. It is fully powered by an *iPad Air 2* and can be used for more than eight hours without charging the battery. The DAC's single stereo 1/4" jack output with adjusted impedance makes it compatible with any guitar amp, pedal, etc.

Several pieces specifically composed for this instrument can be listened to on the BLADEAXE webpage<sup>4</sup>.

<sup>4</sup><https://ccrma.stanford.edu/~rmichon/bladeaxe/> Accessed: 2016-01-18.



**Figure 6:** The final version of the BladeAxe.



**Figure 7:** The textured plate of the BladeAxe.

### 3.1 Control

While the overall shape of the final BLADEAXE is quite similar to its previous version presented in §2, the way it is controlled/performed is very different, mainly because of two versus six blades. Indeed, since we were using an *iPad* as the neck to control parameters such as the pitch of the strings, we thought that the paradigm where strings can be driven independently from the plucking system became obsolete. Instead, the performer is now able to drive any string with a single blade. Pitch is controlled using a chromatic keyboard interface on the screen of the *iPad* (see Figure 8). If one key is pressed, only one virtual string is used. If several keys are touched, several virtual strings are allocated and the excitation from the single blade is routed to these strings.

The BLADEAXE guitar physical model gives access to a pool of ten virtual strings. When the performer presses a key on the screen of the *iPad*, an available string is allocated and its input is activated. If a glissando is performed or if the performer plays an interval smaller than a major third, the same string is used, otherwise, a new string is selected. If several keys are pressed at the same time, then the excitation from the blade is sent to all the activated strings.

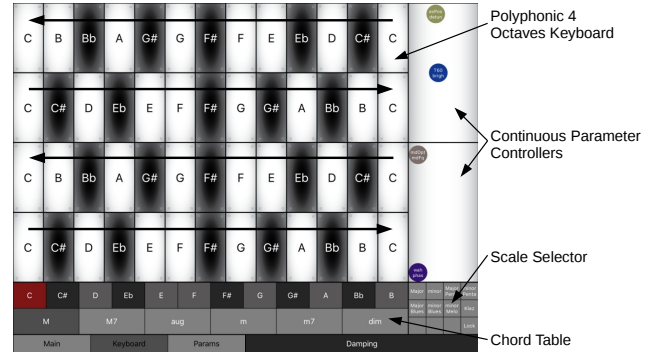
The chromatic keyboard of the BLADEAXE covers four octaves and is arranged as “an S” (see Figure 8) to facilitate slides across several octaves. Thus the lowest key is the one on the top right corner of the interface and the highest one is in the bottom right corner. While this keyboard allows vibrato and sliding between keys, it also “rounds” the pitch of a note when the finger of the performer is not moving. This is very important to make sure that the instrument is not out of tune. The different keys of the keyboard can be highlighted and locked in a specific scale by using the scale selector at the bottom right area of the screen.

The second blade can be used to strum a set of six virtual strings. When an excitation is created, it is progressively sent to the strings with different short delays corresponding to the amount time it would take for the exciter (finger, pick, etc.) to go from one string to another. The duration of this “inter-string-delay” is calculated according to the excitation’s RMS amplitude: the louder the excitation, the faster the strum. Chords can be selected on a table located at the bottom of the interface (see Figure 8) by choosing their root and their type.

Some parameters related to the expressivity of the physical model such as the decay time (T60), brightness, detuning, and material of the strings can be controlled using the “movable dots” located on the right side of the screen. A button located on the bottom of the screen can be used to damp the strings. Finally, each parameter of the physical model can be accessed independently in a parameters menu that can also be used to save presets. More details about the different parameters of the physical models of the BLADEAXE are given in the next section.

### 3.2 Physical Model

The electric guitar physical model of the BLADEAXE is based on a modified version of the *Extended-Karplus-Strong* algorithm [9, 19, 20] and is fully implemented in FAUST<sup>5</sup> [13]. It contains a set of ten virtual strings that can be controlled from the *iOS* layer. They are connected to a series of effects that are directly taken from the FAUST libraries (guitar amp simulator, flanger, phaser, chorus, echo, reverb, distortion, wah pedal, etc.). The virtual strings can be both excited with a signal coming from the plucking system of the



**Figure 8:** User interface of the *iPad* app of the BladeAxe.

BLADEAXE and with a synthesized excitation. The signal coming from the plucking system is lowpass filtered in function of the pitch of the string (lower notes require a lower cutoff frequency than higher notes). Each string waveguide implements a set of two coupled strings using two parallel delay lines (see [20]). Their length can be offset to create harmonics. The amount of offset can be controlled dynamically from the GUI by using the *dots interface* (see §3.1). The length of the delay lines can also be modulated by a sine oscillator to create very expressive effects. The frequency of the modulation and its amplitude can be controlled from the *dots interface* as well.

The pitch of the virtual strings can be changed using a “slide mode” or a “discontinuous mode”. In slide mode, the frequency values are interpolated to create a smooth continuous change. The discontinuous mode can be used to abruptly change the pitch of a string without creating a click. To do that, two parallel delay lines are used. When the pitch of a string is changed, the length of the second delay line is altered and a fast crossfade is carried out to switch from the first delay line to the second one creating a very natural transition.

The model and its associated effects were compiled as a C++ code using the vectorization option of the FAUST compiler. This is very important as this allows us to run all these elements in real-time by utilizing the *iPad Air 2*’s multi-core processor.

## 4. THE PLATEAXE

For our most recent instrument, we wanted to create an interface compatible with the *iPad* app of the BLADEAXE but having a different form factor. Thus the PLATEAXE is intended to be a percussion instrument providing the same kind of laser engraved surfaces as the BLADEAXE and a small plucking interface where a circular polycarbonate disc with variable diameter can be used to generate the sound (see Figure 10). A series of switches and knobs can be used to route the signals of these elements to the different input channels of the BLADEAXE app. Thanks to its non-uniform diameter, the polycarbonate disc creates excitations with different spectra depending on where it is plucked.

## 5. EVALUATION/DISCUSSION

Our first approach [12] consisted in creating an interface as close as possible from the one provided by the original instrument. While we think that we partially achieved this goal with “the right hand” and the plucking system, we struggled much more with the neck. Finding a design of-

<sup>5</sup><http://faust.grame.fr> Accessed: 2016-01-18.

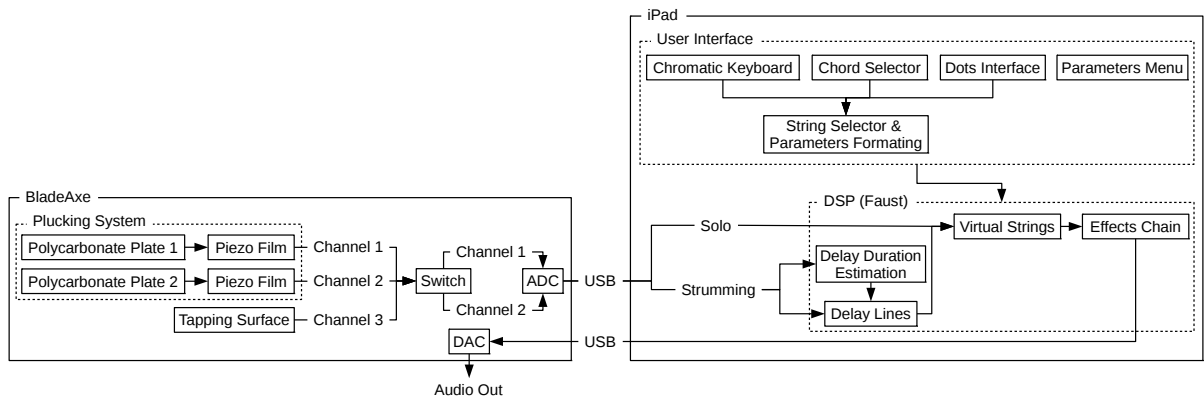


Figure 9: Overview of the implementation of the BladeAxe.

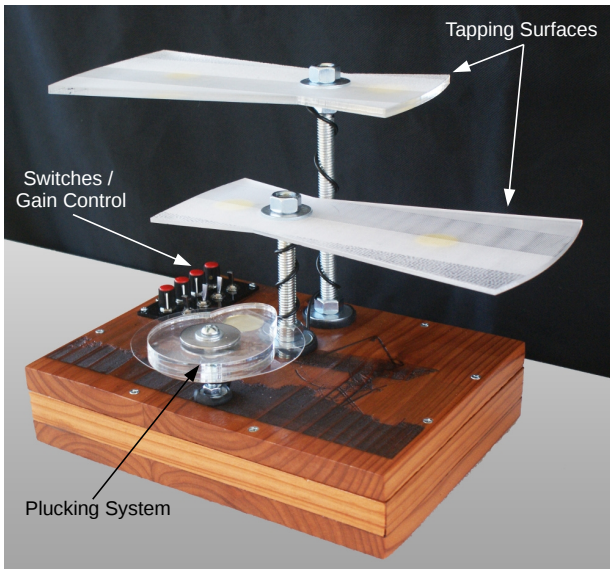


Figure 10: The PlateAxe.

fering the same kind of interactions and sensations than an actual guitar neck prove to be hard. Also, by getting too close to the original instrument, we realized that we lost part of its novelty and that it would never be as good as its purely acoustical counterpart. With the *iPad* version of the BLADEAXE, we think that we found a good compromise between expressivity, skills transfer and novelty.

The ability to control several virtual strings with a single blade made this instrument very intuitive to play. We believe that we could even remove the strumming blade and transfer its functionality to the touch screen interface, allowing to strum and play independent notes with the same blade.

While the textured plate (see figure 7) significantly increases the expressive potential of the BLADEAXE, we think that it could be improved by expanding the diversity of sounds it can produce, perhaps via 3D printing. Indeed, although the current textures all sound different, their spectral content are nonetheless very similar. Varying the shape and the thickness of the plate could help solve this issue.

The first author of this paper has been performing with the latest version of BLADEAXE for about one year. The *iPad* provides a level of stability and robustness competing with professional keyboard synthesizers. After dozens of

performances, the BLADEAXE never crashed or ran out of power. Even though the combined latency of the touch screen and the DAC is about 35 ms (this value is relatively constant), we find it not to be an issue especially after some practice.

Finally, one of the main limitations of using the *iPad* are sweat! Indeed, it often happens during a frenzied performance that the fingers of the performer get clammy or even worse, that a drop of sweat ends up on the touch screen preventing it from working properly.

## 6. FUTURE WORK

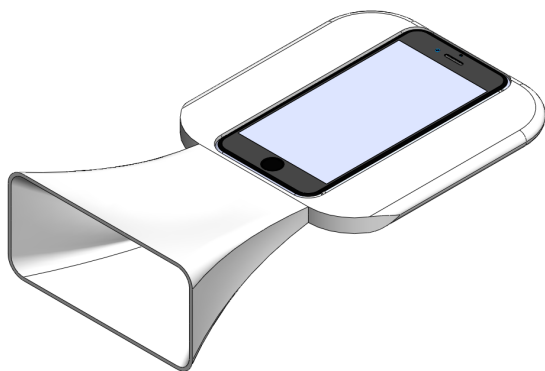
While mobile platforms have been used to create simple musical instruments for almost ten years, we believe that only the latest devices allow the creation of instruments having a comparable expressivity and playability than more sophisticated/standard instruments. However, mobile devices were never meant to be used for this task and are missing crucial elements to make them as playable as a violin, as a guitar, or even as a digital keyboard, etc. We believe that by augmenting those devices using digital fabrication (such as 3D printing) and external sensors (connected passively to the device through the audio jack input or actively by using a micro-controller), we'll be able to design fully standalone mobile-device-based instruments competing with traditional ones. For example, the instrument presented in Figure 11 augments a smart phone with a 3D-printed case integrating a passive acoustic amplifier for its built-in speakers and handles to comfortably play the instrument.

For our next project, we plan to further explore the idea of augmented mobile devices by providing a methodology and a framework to facilitate the design and the creation of such instruments.

## 7. CONCLUSIONS

The BLADEAXE is an *iPad* based musical instrument leveraging the concepts of “augmented mobile device” and “hybrid physical model controller.” By being almost fully standalone, it can be used easily on stage in the frame of a live performance by simply plugging it to a traditional guitar amplifier or to any sound system. Its acoustical plucking system provides the performer with an extended expressive potential compared to a standard controller.

We believe that it opens the way to a new class of “mobile device based hybrid musical instrument” – closer to traditional ones thanks to their acoustical exciters and their general form factor – but also having the advantages offered by digital audio synthesis, in particular physical modeling.



**Figure 11: A smartphone augmented with a 3D printed case.**

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