Passively Augmenting Mobile Devices Towards Hybrid Musical Instrument Design

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ABSTRACT

Mobile devices constitute a generic platform to make standalone musical instruments for live performance. However, they were not designed for such use and have multiple limitations when compared to other types of instruments.

We introduce a framework to quickly design and prototype passive mobile device augmentations to leverage existing features of the device for the end goal of mobile musical instruments.

An extended list of examples is provided and the results of a workshop, organized partly to evaluate our framework, are provided.

Author Keywords

Mobile music technology and performance paradigms, Multimodal expressive interfaces, Novel musical instruments

ACM Classification

H.5.5 [Information Interfaces and Presentation] Sound and Music Computing, D.2.2 [Software Engineering] Design Tools and Techniques, J.5 [Arts and Humanities] Music.

1. INTRODUCTION

Mobile devices (smart-phones, tablets, etc.) have been used as musical instruments for the past ten years both in the industry (e.g., *GarageBand*[1] for iPad, Smule's apps,[2] moForte's *GeoShred*,[3] etc.) and in the academic community [5, 14, 13, 6, 4, 2, 15]. As stand alone devices they present a promising platform for the creation of versatile instruments for live music performance. Within a single entity, sounds can be generated and controlled, differentiating them from most Digital Musical Instruments (DMIs), and allowing the creation of instruments much closer to "traditional" acoustic instruments in this respect. This resemblance is pushed even further with mobile phone orchestras such as *MoPhO*[4] [16], where each performer uses a mobile phone as a independent musical instrument.

Despite all these qualities, mobile devices were never designed to be used as musical instruments and lack some crucial elements to compete with their acoustic counterparts. In a previous publication [10], we introduced the concept of "augmented mobile-device" and we presented the BladeAxe: a hybrid instrument partly based on acoustic elements and an iPad. The iPad was used both as a controller, and to implement virtual physical-model-based elements of the instrument. The BladeAxe was the last iteration of a series of mobile-device-based instruments that we developed during the past four years.

In this article, we try to generalize the concept of "augmented mobile device" and we provide a framework to facilitate the design of this kind of instrument. We focus on "passive augmentations" leveraging existing components of hand-held mobile devices in a very lightweight, non-invasive way (as opposed to "active augmentation" requiring the use of electronic components).

We'll introduce Mobile3D, an `OpenScad`[5] library to help design mobile device augmentations using DIY (*Do It Yourself*) digital fabrication techniques such as 3D printing and laser cutting. We'll give an exhaustive overview of the taxonomy of the various types of passive augmentations that can be implemented on mobile devices through a series of examples and we'll demonstrate how they leverage existing components on the device. Finally, we'll evaluate our framework and propose future directions for this type of research.

The software implementation of the instruments presented in this study will not be discussed. Most of them were made using the SmartKeyboard App Generator.[6]

2. MOBILE 3D

Mobile3D is an `OpenScad` library facilitating the design of mobile device augmentations. `OpenScad` is an open-source Computer Assisted Design (CAD) software using a high level functional programming language to specify the shape of any object. It supports fully parametric parts, permitting users to rapidly adapt geometries to the variety of devices available on the market.

Mobile3D is organized in different files that are all based on a single library containing generic standard elements (`basics.scad`) ranging from simple useful shapes to more advanced augmentations such as the ones presented in the following sections. A series of device-specific files adapt the elements of `basics.scad` and are also available for the *iPhone 5*, *6*, and *6 Plus* and for the *iPod Touch*. For example, a generic horn usable as a passive amplifier for the built-in speaker of a mobile device can be simply created

[1] `http://www.apple.com/ios/garageband` – All the URLs in this paper were verified on 04/07/17.
[2] `https://www.smule.com`
[3] `http://www.moforte.com/geoshredapp`
[4] `http://mopho.stanford.edu`
[5] `http://www.openscad.org`
[6] `https://ccrma.stanford.edu/~rmichon/smartKeyboard`

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with the following call in `OpenScad`:

```
include <basics.scad>
SmallPassiveAmp();
```

The corresponding 3D object can be seen in Figure 1.

Figure 1: CAD model of a generic passive amplifier for the built-in speakers of a mobile device.

To generate the same object specifically for the *iPhone 5*, the following code can be written:

```
include <iPhone5.scad>
iPhone5_SmallPassiveAmp();
```

Finally, the shape of an object can be easily modified either by providing parameters as arguments to the corresponding function, or by overriding them globally before the function is called. If this approach is chosen, all the parts called in the `OpenScad` code will be updated, which can be very convenient in some cases. For example, the radius (expressed in millimeters here) of `iPhone5_SmallPassiveAmp()` can be modified locally by writing:

```
include <iPhone5.scad>
iPhone5_SmallPassiveAmp(hornRadius=40);
```

or globally by writing:

```
include <iPhone5.scad>
iPhone5_SmallPassiveAmp_HornRadius = 40;
iPhone5_SmallPassiveAmp();
```

Mobile3D is based on two fundamental elements that can be used to quickly attach any prosthetic to the device: the top and bottom *holders* (see Figure 2). They were designed to be 3D printed using elastomeric material such as *NinjaFlex*®[7] in order to easily install and remove the device without damaging it. They also help reducing printing duration, which is often a major issue during prototyping. These two holders glued to a laser-cut plastic plate form a sturdy case (as shown in Figure 2), whereas completely printing this part would take much more time.

[7]`https://ninjatek.com`

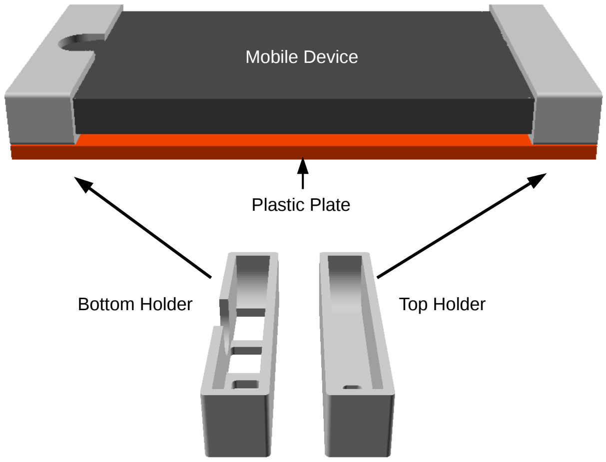

Figure 2: CAD model of a simple *iPhone 5* case made from 3D -printed holders and a laser-cut plastic plate.

A wide range of elements can be easily added to the basic mobile phone case presented in Figure 2 by using adhesives. Some of them will be presented in greater details in the following sections and are part of Mobile3D.

Figure 3 presents an example of an *iPhone 5* augmented with a passive amplifier similar to the one presented above. The bottom holder and the horn were printed separately and glued together, but they could also have been printed as one piece. In this example, the bottom and top holders were printed with PLA,[8] which is a hard plastic, and they were mounted on the plate using Velcro ®. This is an alternative solution to using *NinjaFlex* ® that can be useful when augmenting the mobile device with large appendixes requiring a stronger support.

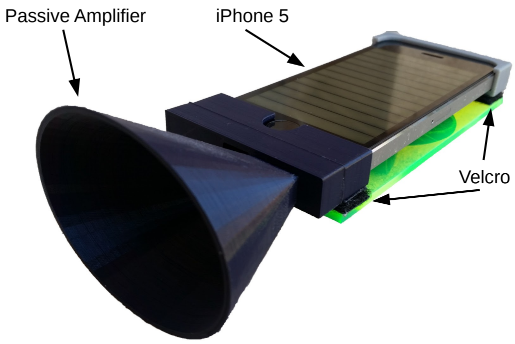

Figure 3: *iPhone 5* augmented with a horn used as passive amplifier on its built-in speaker (instrument by Erin Meadows).

The passive amplifier presented in Figure 3 was made by overriding the default parameters of the `iPhone5_SmallPassiveAmp()` function:

```
include <lib/iPhone5.scad>
iPhone5_SmallPassiveAmp_HornLength = 40;
iPhone5_SmallPassiveAmp_HornRadius = 40;
iPhone5_SmallPassiveAmp_HornDeformationFactor
     = 0.7;
iPhone5_SmallPassiveAmp();
```

[8]PolyLactic Acid.

An exhaustive list of all the elements available in MOBILE3D can be found on the project webpage.[9]

3. LEVERAGING BUILT-IN SENSORS AND ELEMENTS

Mobile devices host a wide range of built-in sensors and elements that can be used to control sound synthesizers [2, 6]. While the variety of available sensors and elements differs from one device to another, most smart-phones have at least a touch screen, a loudspeaker, a microphone, and some type of motion sensor (accelerometer, gyroscope, etc.). In this section, we'll focus on these four elements and we'll demonstrate how they can be "augmented" for specific musical applications.

3.1 Microphone

While the built-in microphone of a mobile device can simply serve as a source for any kind of sound process (e.g., audio effect, physical model, etc.), it can also be used as a versatile, high rate sensor. [12] In this section, we demonstrate how it can be augmented for different kinds of uses.

3.1.1 Amplitude-Detection-Based Augmentations

One of the first concrete uses of the built-in microphone of a mobile device to control some sound synthesis process was done with Smule's Ocarina[10] [15]. There, the microphone serves as a blow sensor by measuring the gain of the signal created when blowing on it to control the gain of an ocarina sound synthesizer.

MOBILE3D contains an object that can be used to leverage this principle when placed in front of the microphone (see Figure 4). It essentially allows the performer to blow into a mouthpiece mounted on the device. The air-flow is directed through a small aperture inside the pipe, creating a sound that can be recorded by the microphone and analyzed in the app using standard amplitude tracking techniques. The air-flow is then sent outside of the pipe, preventing it from ever being in direct contact with the microphone.

The acquired signal is much cleaner than when the performer blows directly onto the mic, allowing to generate precise control data. Additionally, condensation never accumulates on the mic which can help extend the duration of its life, etc.

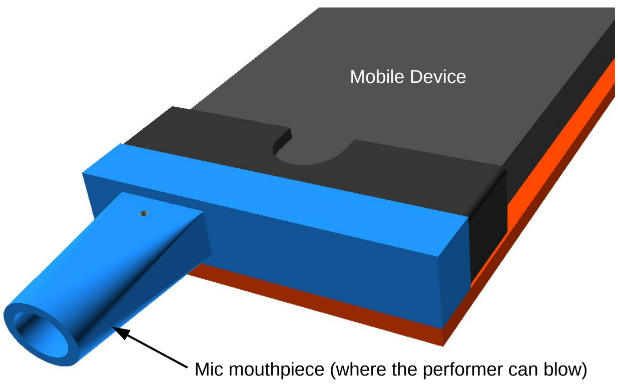

Figure 4: Mouthpiece for mobile device built-in mic.

[9] https://ccrma.stanford.edu/~rmichon/mobile3D

[10] https://www.smule.com/ocarina/original

3.1.2 Frequency-Detection-Based Augmentations

The built-in microphone of mobile devices has already been used as a data acquisition system to implement various kinds of sensors using frequency analysis techniques [7]. MOBILE3D contains an object using similar principles that can be used to control some of the parameters of a synthesizer running on a mobile device. It is based on a conical tube (see Figure 5) where dozens of small tines of different length and diameter are placed inside it. These tines get thicker towards the end of the tube and their length varies linearly around it. When the performer blows inside the tube, the resulting airflow hits the nails, creating sounds with varying harmonic content. By directing the airflow towards different locations inside the tube, the performer can generate various kind of sounds that can be recognized in the app using frequency analysis techniques. The intensity and the position of the airflow around the tube can be measured by keeping track of the spectral centroid of the generated sound, and used to control synthesis parameters.

The same approach can be used with an infinite number of augmentations with different shapes. While our basic spectral-centroid-based analysis technique only allows us to extract two continuous parameters from the generated signal, it should be possible to get more of them using more advanced techniques such as those used with MOGEES[11] [1].

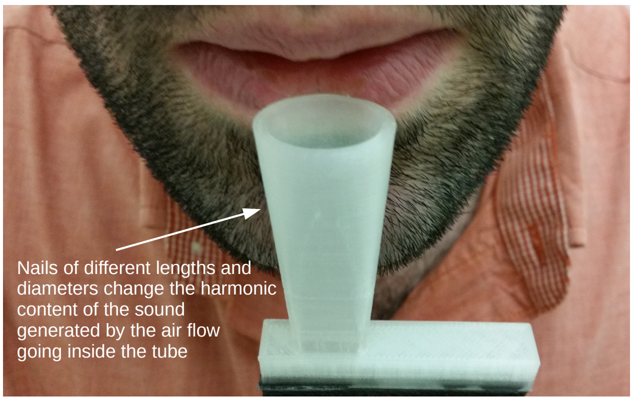

Figure 5: Frequency-based blow sensor for mobile device built-in microphone.

3.2 Speaker

Even though their quality and power has significantly increased during the last decade, mobile device built-in speakers are generally only good for speech, not music. This is mostly due to their small size and the lack of a proper resonance chamber to boost bass, resulting in a very curvy frequency response and a lack of power.

There exists a wide range of passive amplifiers on the market to boost the sound generated by the built-in speakers of mobile devices, also attempting to flatten their frequency response. These passive amplifiers can be seen as resonators driven by the speaker. In this section, we present various kinds of resonators that can be connected to the built-in speaker of mobile devices to amplify and/or modify their sound.

3.2.1 Passive Amplifiers and Resonators

MOBILE3D contains multiple passive amplifiers of various kinds that can be used to boost the loudness of the built-in speaker of mobile devices (e.g., see Figure 3). Some of

[11] http://www.mogees.co.uk

them were designed to maximize their effect on the generated sound [3]. Their shape can vary greatly and will usually be determined by the type of the instrument. For example, if the instrument requires the performer to make fast movements, a small passive amplifier will be preferred to a large one, etc. Similarly, the orientation of the output of the amplifier will often be determined by the way the performer holds the instrument, etc. These are design decisions that are left up to the instrument designer.

3D printed musical instrument resonators (e.g., guitar body, etc.) can be seen as a special case of passive amplifiers. MOBILE3D contains a few examples of such resonators that can be driven by the device's built-in speakers. While they don't offer any significant advantage over "standard" passive amplifiers like the one presented in the previous paragraph, they are aesthetically interesting and perfectly translate the idea of "hybrid lutherie" developed in [10] and that we emphasize in this study.

3.2.2 *Dynamic Resonators*

Another way to use the signal generated by the built-in speakers of mobile devices is to modify it using dynamic resonators. For example, in the instrument presented in Figure 6, the performer's hand can filter the generated sound to create a *wah* effect. This can be very expressive, especially if the signal has a dense spectral content. This instrument is featured in the teaser video [11] of the workshop presented in §5.

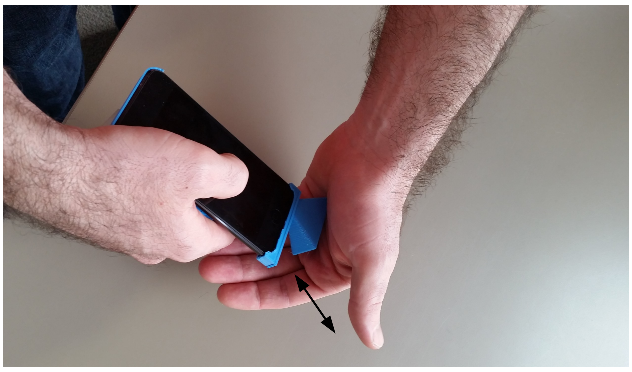

Figure 6: Hand resonator for mobile device built-in speaker.

Similarly, the sound generated by the built-in speaker is sent to the mouth of the performer in the instrument presented in Figure 7. The sound is therefore both modulated acoustically and through the embedded synthesis and touchscreen. The same result can obviously be achieved by directly applying the mouth of the performer to the speaker, but the augmentation presented in Figure 7 increases the effect of the oral cavity on the sound through a passive wave guide.

3.3 Motion Sensors

Most mobile devices have at least one kind of built-in motion sensor (e.g., accelerometer, gyroscope, etc.). They are perfect to continuously control the parameters of sound synthesizer and have been used as such since the beginning of "mobile music" [2].

Augmentations can be made to mobile devices to direct and optimize the use of this type of sensor. This kind of augmentation can be classified in two main categories:

- augmentations to create specific kinds of movements (spin, swing, shake, etc.),

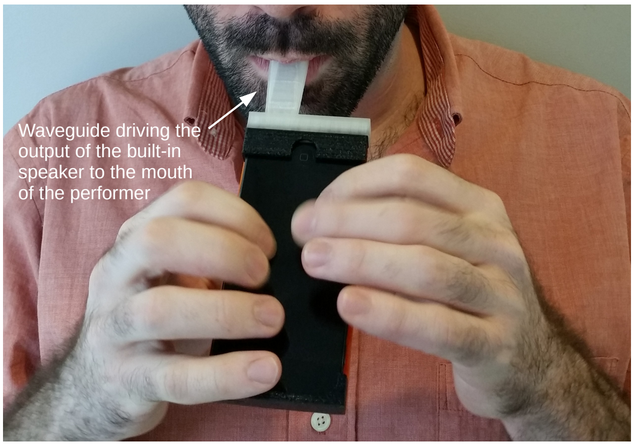

Figure 7: Mouth resonator for mobile device built-in speaker.

- augmentations related to how the device is held.

Figure 8 presents a "sound toy" where a mobile device can be spun like a top. This creates a slight "Leslie effect", increased by the passive amplifier. Additionally, the accelerometer and gyroscope data are used to control the synthesizer running on the device. This instrument is featured in the teaser video [11] of the workshop presented in §5.

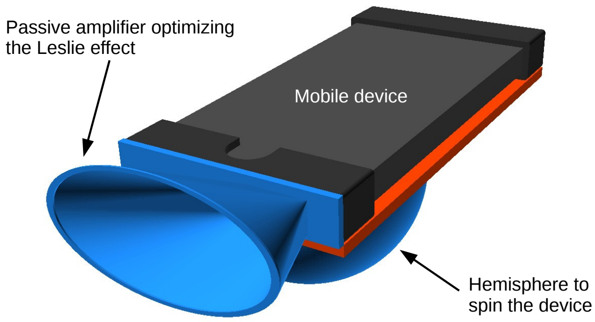

Figure 8: Mobile-device-based top creating a "Leslie" effect when spun.

Another example of motion-sensor-based augmentation is presented in Figure 13 and described with more details in §5. It features a smart-phone mounted on a bike wheel [8] where, once again, the gyroscope and accelerometer data are used to control the parameters of a synthesizer running on the device. Similarly, a "rolling smart-phone" is presented in Figure 12 and described in §5. MOBILE3D contains a series of templates and functions to make this kind of augmentation.

Augmentations leveraging built-in sensors related to how the device is held are presented in more detail in §4.

3.4 Other Sensors

Most mobile devices host built-in sensors that exceed the ones presented in the previous sections and are not supported yet in MOBILE3D. For example, built-in cameras can be used as very versatile sensors, [12] and a wide range of passive augmentations could be applied to them to "customize" their use for musical ends (see §6). We plan to support more sensors in MOBILE3D in the future.

4. HOLDING MOBILE DEVICES

Mobile devices were designed to be held in a specific way, mostly so that they can be used conveniently both as a phone and to use the touch-screen. Passive augmentations can be designed to hold mobile devices in different ways to help carry out specific musical gestures, better leveraging the potential of the touch-screen and of built-in sensors.

More generally, this type of augmentation is targeted towards making mobile-device-based musical instruments more engaging and easier to play.

In this section, we give a brief overview of the different types of augmentations that can be made with MOBILE3D to hold mobile devices in different ways.

4.1 Wind Instrument Paradigm

One of the first attempts to hold a smart-phone as a wind instrument was Smule's Ocarina [15], where the screen interface was designed to be similar to a traditional ocarina. The idea of holding a smart-phone as such is quite appealing since all fingers (beside the thumbs) of both hands perfectly fit on the screen (thumbs can be placed on the other side of the device to hold it). However, this position is impractical since at least one finger has to be on the screen in order to hold the device securely. The simple augmentation presented in Figure 9 solves this problem by adding "handles" on both sides of the device so that it can be held using the palm of the two hands, leaving all fingers (including the thumbs) free to carry out any action. Several functions and templates are available in MOBILE3D to design these types of augmentations.

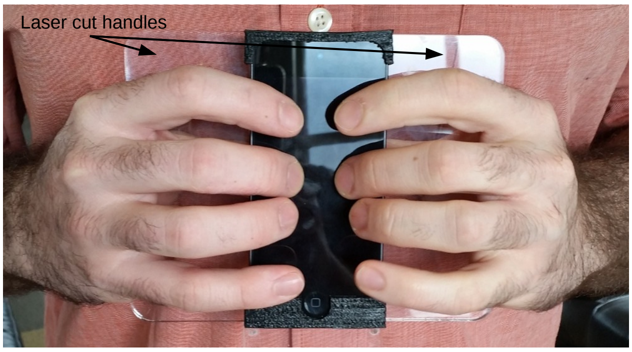

Figure 9: Smart-phone augmented to be held as a wind instrument.

4.2 Holding the Device With One Hand

MOBILE3D contains several functions and templates to hold mobile devices with one hand, leaving at least four fingers available to perform on the touch-screen. This way to hold the device opens up a wide range of options to fully take advantage of the built-in motion sensors and easily execute free movements. Additionally, the performer can decide to use two devices in this case (one for each hand).

The instrument presented in Figure 10 uses one of MOBILE3D's ring holders to hold the device with only the thumb. Similarly, Figure 11 features an instrument held in one hand using a laser-cut plastic handle mounted on the device.

4.3 Other Holding Options

There are obviously many other options to hold mobile-devices to carry out specific musical gestures. For example, one might hold the device in one hand and perform it with the other, etc. In any case, we believe that MOBILE3D provides enough options to cover the design needs for most musical instruments.

Figure 10: Thumb-held mobile-device-based musical instrument (by Erin Meadows).

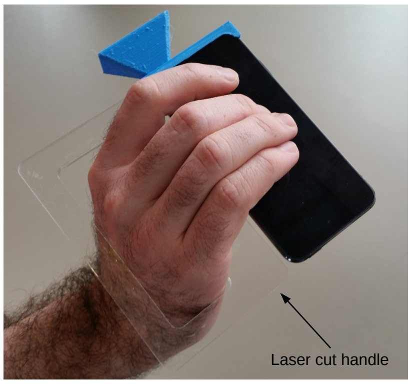

Figure 11: Single-hand-held musical instrument based using a laser-cut plastic handle.

5. MORE EXAMPLES AND EVALUATION

To evaluate MOBILE3D and the framework presented in this paper, we organized a one-week workshop last summer at Stanford's *Center for Computer Research in Music and Acoustics* (CCRMA) called *The Composed Instrument Workshop: Intersections of 3D Printing and Digital Audio for Mobile Platforms* [8, 9]. We taught the seven participants how to make basic musical smart-phone apps using our SMARTKEYBOARD APP GENERATOR and how to use MOBILE3D to design mobile device augmentations. They were free to make any musical instrument or sound toy for their final project [9]. Some examples of these instruments are presented in Figures 3, 12 and 13.

In only one week, participants mastered all these techniques and designed and implemented very original instrument ideas. This helped us debug and improve MOBILE3D with new objects and features.

6. FUTURE DIRECTIONS

In this paper, we only talked about the physical part of musical instruments based on augmented mobile devices. As we explained previously, we believe that mobile-devices offer a great opportunity to make DMIs with a strong coherence between the virtual (screen interface, synthesizer, etc.) and the physical (hardware augmentations, physical elements playing role in the sound generation process, etc.) part of the instrument. Additionally, through various kinds of augmentations combined with intelligent interfaces, they can help performers to transfer a part of their skills to play them.

Just like MOBILE3D, the SMARTKEYBOARD APP GENERATOR was designed to help musical instrument designers

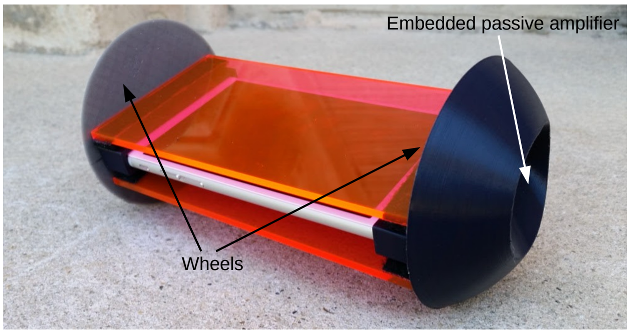

Figure 12: Rolling mobile phone with phasing effect (instrument by Revital Hollander).

Figure 13: Mobile device mounted on a bike wheel (instrument by Patricia Robinson).

to solve these problems as a whole. We plan to conduct a study treating these aspects.

We only talked about passive augmentations here, and we should obviously not be limited to them. Indeed, modern micro-controller boards such as the *Arduino*[12] or *Teensy*[13] can easily be used to acquire sensor data and transmit it to mobile devices. Thus, we plan to further our investigation to see what kind of active augmentations can be added to mobile devices to turn them into musical instruments.

7. CONCLUSIONS

Mobile devices constitute an appealing platform to design digital musical instruments for live performance, bridging the often broken link between interface, musical gesture and sound synthesis (which is quite recurring in this family of instruments).

The deficits of mobile devices can be easily mitigated by augmenting them with various kinds of prosthetics leveraging some of their built-in components and sensors. This opens the path to a new approach to "digital lutherie" to make completely standalone "hybrid" instruments, centered on mobile devices, where some of their components belong to the virtual world, and others to the physical world.

Lots of work remains to be done to provide a comprehensive solution to help design this type of instruments. We believe that MOBILE3D is the first brick in wall that will keep growing.

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