Rouages: Revealing the Mechanisms of Digital Musical Instruments to the Audience

Florent Berthaut
Potioc, LaBRI
University of Bordeaux
florent.berthaut@labri.fr

Mark T. Marshall
Department of Computer Science
University of Bristol, UK
mark.t.marshall@bristol.ac.uk

Sriram Subramanian
Department of Computer Science
University of Bristol, UK
sriram.subramanian@bristol.ac.uk

Martin Hachet
Potioc, LaBRI
INRIA Bordeaux Sud-Ouest
martin.hachet@inria.fr

ABSTRACT

Digital musical instruments bring new possibilities for musical performance. They are also more complex for the audience to understand, due to the diversity of their components and the magical aspect of the musicians' actions when compared to acoustic instruments. This complexity results in a loss of liveness and possibly a poor experience for the audience. Our approach, called *Rouages*, is based on a mixed-reality display system and a 3D visualization application. *Rouages* reveals the mechanisms of digital musical instruments by amplifying musicians' gestures with virtual extensions of the sensors, by representing the sound components with 3D shapes and specific behaviors and by showing the impact of musicians' gestures on these components. In its current implementation, it focuses on MIDI controllers as input devices. We believe that *Rouages* opens up new perspectives for instrument makers and musicians to improve audience experience with their digital musical instruments.

Keywords

rouages; digital musical instruments; mappings; 3D interface; mixed-reality;

1. INTRODUCTION

The variety of digital musical instruments (DMI) is continuously increasing, with a plethora of commercial software and hardware production (e.g. the Reactable, the Monome or the Novation Launchpad) and with the development of prototyping platforms and languages. Electronic musicians are now able to create their own instruments easily, each with very specific sets of sensors, sound processes/modules and mappings [7] between the gestures/sensors and sound parameters, all of which can be different from other musicians. While this diversity allows the electronic musicians to creatively express themselves it can often be confusing to the audience. Research done on recreating the link between gestures and digital sound for musicians should now also consider this link from the audience point of view.

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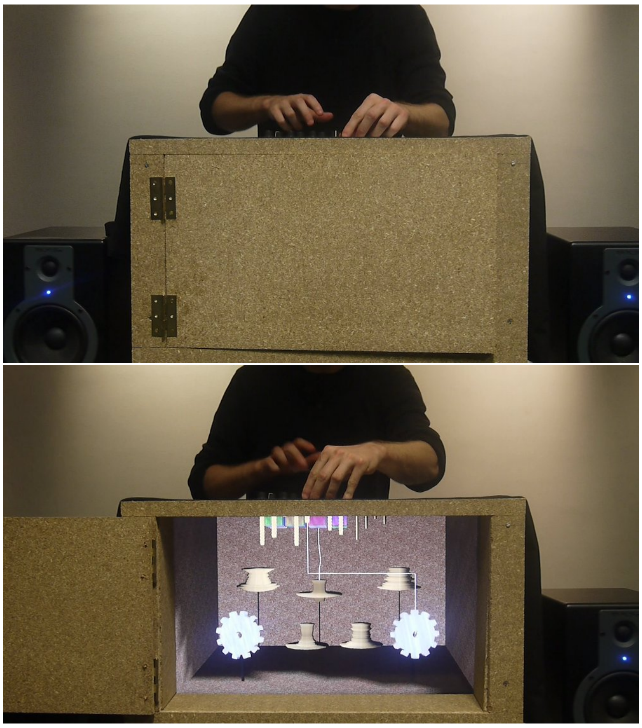

Figure 1: A digital musical instrument composed of 16 pads, 8 knobs, 4 faders, two audio loops and 5 synthesizers, without (top) and with (bottom) Rouages

1.1 Audience experience in electronic music performances

Members of the audience of electronic music performances have little or no information about the DMIs being played and in contrast to acoustic instruments, they cannot deduce the behavior of DMIs from familiar physical properties such as material, shape, and size. To add to this confusion, the most common configuration in these performances is a set of sensors, or sometimes simply a laptop, laid on a table on the stage. The sensors themselves are then difficult for the audience to see. The same is true for the small gestures that musicians make when performing. According to [14], performances with DMIs would be classified as magical, i.e. manipulations are hidden while their effects are known. Recent work by Marshall et al. [13] indicates that the perceived liveness of DMIs, which involves the identification of relationships between gestures and resulting sound, impacts on the emotional response of members of the audience. When the perceived liveness is low, as in the case of laptop performances, members of the audience might even think that musicians only click on a play button and then spend the entire performance reading their emails while shaking their head [5]. In short, a key problem in enhancing the audience experience with DMIs is to make the performance less magical and more expressive, so that members of the audience perceive the involvement of musicians.

1.2 Musicians strategies

Recognizing this need to enhance audience experience, some musicians adopt different strategies to overcome this lack of visibility of their actions. The controller is sometimes tilted as done by Moldover [1] or filmed and reprojected as in Hifana's performances [2] or in Bjork's performances with the Reactable [3]. However, the impact of musicians' gestures on the sound is still hard to understand because one sensor may be mapped to several sound parameters and because DMIs are often multiprocess instruments, i.e. instruments composed of several sound processes that may produce sound independently from musicians' actions. In addition, when a re-projection is used the spatial consistency, i.e. collocation of the musician and the instrument, is broken. According to Armstrong [1], "the perceptual localization of the origin of the sound is an important indicator of the instrument's phenomenal presence, both for the performer, fellow performers, and the audience". This also applies to the visual feedback that combines the musician and instrument and the virtual representation. In addition, when members of the audience watch a close-up of the sensors they miss the additional accompanying gestures that also contribute to the liveness of the performance [15]. More recently, some electronic musicians such as Danger [4] have used a video projection of the graphical user interface of their DMI. This provides some feedback on the modules of the instrument, but once again information such as accompanying gestures, the link between gestures and sound, and the precise behavior of the DMI are hidden.

One may argue that graphical interfaces used in digital musical instruments such as the Reactable [9], FMOL [8], Different strokes [16] or Sound from shapes [11], while providing valuable feedback and control possibilities for musicians as pointed out by Jordà [8], also give the audience enough information to understand the instrument. However these instruments may also confuse members of the audience because of occlusions due to musicians' gestures, the small size of the interface and non-collocated re-projections hiding non-musical gestures. Finally the high level of detail needed by musicians to properly control the instrument, e.g. the complete graph in the Reactable or additional graphical elements which do not directly affect the sound, may prevent members of the audience from properly understanding both the impact of musicians on the sound and the structure of the instrument. Instead of relying on musicians' interfaces that are specific to each instrument, we believe that dedicated graphical interfaces should be developed for the audience, which are collocated with the musicians and which include simplified representations of DMIs components, with generic behaviors that members of the audience can become accustomed to.

[1]http://www.youtube.com/watch?v=bOKIRNg_rKI
[2]http://www.youtube.com/watch?v=HFi-pKap3Vc
[3]http://www.reactable.com/videos/bjork_paris.mp4
[4]http://vimeo.com/23213096

In this paper, we present *Rouages*, a mixed-reality 3D visualization system that is designed to improve the audience experience by revealing the mechanisms of digital musical instruments. *Rouages* consists of a hardware part that in its current form handles MIDI controllers and other tabletop input devices of DMIs and of a software application that simulates the inner mechanisms of the instrument through a 3D rendering. The main contributions of this paper are threefold: 1) a mixed-reality system that extends DMIs sensors with virtual counterparts to amplify musicians' gestures, 2) 3D representations of the dynamically analyzed sound processes of the instruments to reveal how the sound is produced, 3) dynamic links between virtual sensors and visualized sound processes to show how musicians impact the sound.

2. ROUAGES

2.1 General Approach

A typical DMI, as depicted in Figure 2, is broadly made of three layers: the input device with sensors, a mapping layer to process/combine data from the sensors, and a sound layer composed of sound processes and modules with controllable parameters. For example, in the case of a DJ, one of the sensors would be a linear potentiometer whose value would be processed by a mapping layer to control simultaneously the volumes of two sound processes, increasing one volume while decreasing the other. In order to give the audience a better perception of how a DMI produces sound and of how musicians control it, *Rouages* uses three distinct approaches that are different from previous attempts.

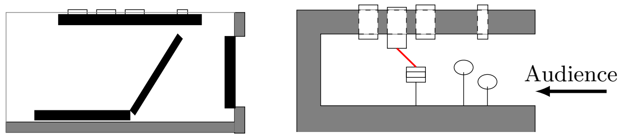

Figure 3: Left: Side view of the physical *Rouages* system: tiltable controller, room for the laptop, screen facing the audience. Right: Side view of the mixed-reality box as perceived by the audience (with one pad pressed).

- *Virtually extending sensors:* We amplify the musicians' gestures by virtually extending the sensors so that the audience can see small/hidden gestures.
- *3D representation of the sound modules:* We visualize the sound production with 3D representations of the sound modules so that members of the audience can understand the sonic structure and behavior of the instrument.
- *Link virtual sensors with sound modules:* We reveal the impact of gestures by linking the virtual sensors and the sound modules, so that the audience can understand how the musicians are actually modifying the sound.

These three steps are defined in the next sections.

Rouages is composed of a mixed reality hardware setup as depicted in Figure 3 and a software application that gathers data from the sensors and the sound modules.The current hardware part is oriented towards MIDI controllers as input devices as these remain the most common choice for electronic music performances. However, the same approach can be adapted with gestural controllers or multitouch surfaces, provided that the manipulated sensors or widgets can be tracked. Common sensors on MIDI controllers include linear potentiometers (faders), angular potentiometers (knobs), and pressure / contact sensors such as buttons and drum pads. These controllers are usually placed on a table and often tilted either towards the musicians or

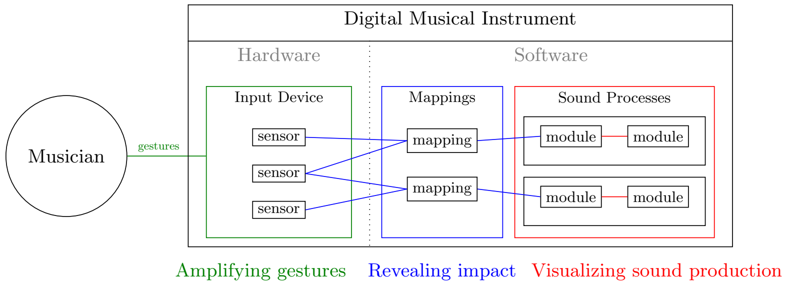

Figure 2: Structure of a Digital Musical Instrument and steps of the Rouages approach

towards the audience, therefore changing the sensors visibility. They are mostly used in combination with a laptop computer which might hide the controller. The hardware part of our prototype is a box made so that musicians can tilt their controller and see their laptop as they do with their current setup. As shown on Figure 3, the controller is placed above the box and the laptop inside it. A screen is placed on the front side of the box, which has an opening. This screen is used to display a virtual scene inside of the box, containing 3D virtual parts attached to the real sensors and 3D representations of the sound modules of the DMI.

2.2 Amplifying gestures by virtually extending sensors

Figure 4: Two different controllers (seen from above) and the associated sets of virtual sensors extensions (seen from below)

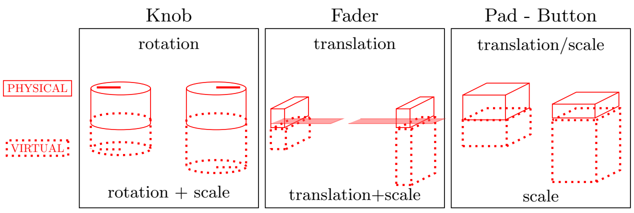

Figure 5: Physical sensors transformations and their amplifications by virtual sensors extensions

In the context of public performances with MIDI controllers, used sensors are small, distant, and often grouped, therefore hiding each other. Moreover, musicians' gestures are often unnoticeable. The first step of *Rouages* consists in extending the physical sensors with virtual counterparts in order to graphically amplify sensor movements and their associated gestures. Each sensor has a specific virtual extension attached to it through the top of the box, as depicted in Figure 5. In order to be effectively associated with the sensors, these virtual extensions must be spatially merged using a 3D visualization matching the point of view of the audience. To that extent, positions and orientations of the controller, as well as positions of the screen and of the audience, are tracked. This approach is similar to the idea of Collapsible Tools developed in [10]. However, in *Rouages* the virtual augmentation is used for visualization, not interaction. We define three strategies for amplifying visibility of sensors, especially within groups. The first is to add a virtual transformation to the physical one, as depicted in Figure 5. The second is to differentiate sensors that are grouped and potentially occluding each other by modulating their heights and colors. The third is to take advantage of screens larger than controllers to increase the size of / extend the virtual counterparts. For instance, mechanical arms can be used to amplify the movements of virtual sensors. These last two strategies are demonstrated on a group of pads on Figure 6.

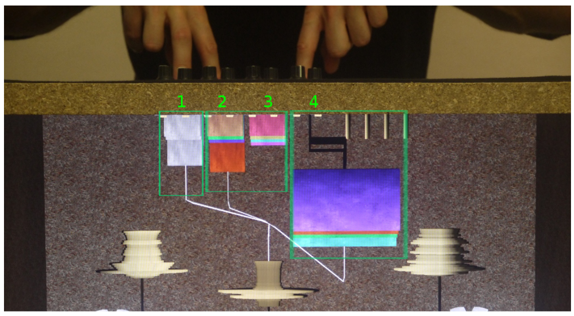

Figure 6: Grid of 16 pads being played. First column with undifferentiated gray pads. Second and third columns with different colors for each pad. Fourth column with colored extended virtual pads.

2.3 Representing the audio modules/processes

The second step of our approach consists in revealing how sound is generated in DMIs. To that extent, modules of sound processes are represented by 3D objects placed inside the virtual box. The activity of each module can be visualized by changing graphical parameters of the associated 3D object based on audio analysis done on its sound output and on control data coming from the sensors.

Three issues arise with this step of our approach. The first relates to the level of detail of the representation of the sound processes. While it is possible to visualize all modules of all sound processes of the instrument, this may lead to visual clutter, which may affect the audience understanding of the instrument. The visualization of several modules can therefore be combined on a single 3D object. The representation of their impact may then be shown by using different graphical parameters of the same object, as done in [2] and formalized in [6]. For example, a pitch shifter applied to an audio loop can be visualized by changing the color of the loop visualization when the pitch is modified. Some

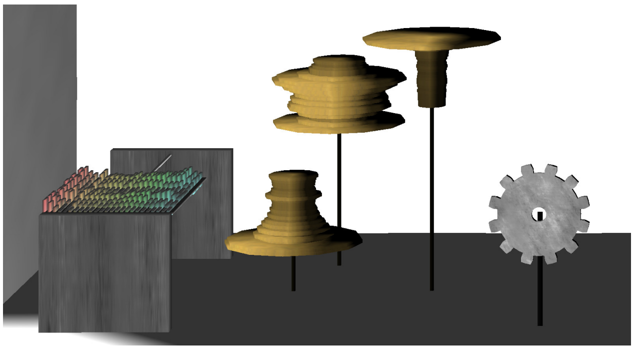

Figure 7: Left: A playlist module displaying the audio spectrum on a sequence of 3D elements. Center: Three synthesizer modules with shapes displaying the spectrum of the produced sounds. Right: A generic audio loop module, with rotation speed mapped to the loudness of the loop.

sound modules can also be hidden because their impact on the resulting sound can not be discriminated, for example when it is too subtle or when it does not vary during the performance.

Second, when representing whole sound processes as single 3D objects, rather than completely specifying their representation, we define *behaviors* for the three following categories of processes: *playlists*, *loops* and *synthesizers*. These behaviors illustrate the associated level of interruption tolerance that these categories represent as explained in [12], from completely written and autonomous to completely passive without musician actions. They also relate to the freedom of the musicians as described in [8].

- *Playlists/scores* have a high level of tolerance to interruption. They consist in predefined / written musical events that provide interesting musical results without any actions of the musician, and that will be manipulated using effects. Since they do not involve repetition, but rather a complete predefined sequence, the behavior of the associated objects is a linear non-cyclic motion / variation. They may also originate from outside the virtual box, to illustrate that the musicians have limited control over them.

- *Loops* may also be predefined but they need more manipulations in order to provide an interesting musical result. The behavior of the associated objects should be a periodic motion / variation, in order to show that they are partly written. They should be completely contained in the virtual box in contrast to *Playlists*.

- *Synthesizers* need to be activated in order to produce any sound. The musician has a complete control over them. The behavior of the associated objects is therefore an absence of motion, which reveals their passivity.

Each of these behaviors can obviously be represented in many different ways. The last issue for this step of our approach is therefore the specialization of module representations. Indeed, representations should be chosen so that they give enough information on what the sound modules do, in particular to ensure that members of the audience can deduce what is generated by each represented module, without overloading the instrument visualization. The information may be extracted only from the modules audio output. It may also be combined with sensors values, especially for sound parameters that are harder to analyze.

Three examples of representations are depicted on Figure 7. In the case of synthesizers, the passive behavior is combined with a fast loudness analysis and a slower Bark bands spectrum analysis in order to give a different shape and activity to each representation. Bark bands amplitudes control the diameters of piled cylinders from the lowest frequency for the bottom one to the highest frequency for the top one. The signal loudness gives the overall scale of the shape. Therefore, when synthesizers are not played, their shapes indicate which sounds they represent, e.g. bass or cymbals, allowing member of the audience to identify each of them. When played, variations of their scales following the loudness provide additional information.

Loops in our example have a less detailed representation. Their cyclic behavior and their activity are displayed at the same time by mapping the loudness of the sound to the speed of the rotation. Therefore, when the loop is either stopped or silent, the rotation stops. With more advanced audio analysis, such as repetition detection, the shape could also be used to display the entire waveform of the loop as its contours, and the speed could be mapped to the actual detected speed of the loop.

Finally, for the playlist behavior we use the metaphor of the barrel organ. A chain of 3D elements comes out of a pipe at a speed that is mapped to the sound loudness. The playlist therefore originates from outside the box and is revealed as it plays. The sound output is analyzed and the spectrum and loudness are used to define the shape of the upcoming element, therefore mimicking physical punched cards.

2.4 Revealing the impact of gestures on the sound

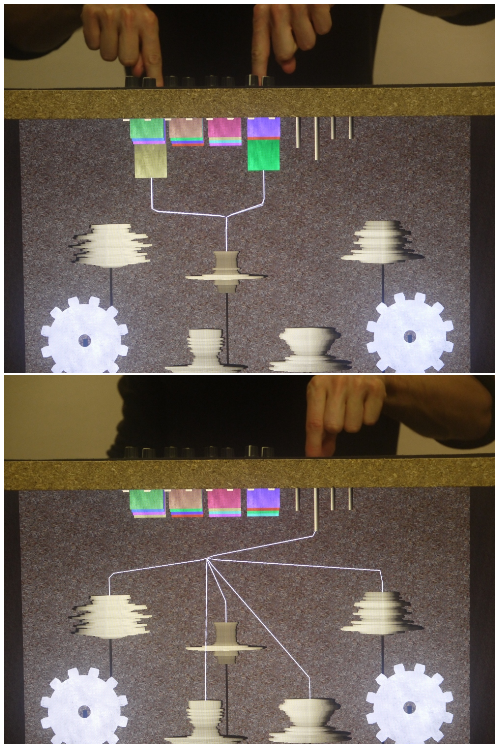

Figure 8: Top: Merging the links from two pads to a synthesizer. Bottom: Splitting the link from a fader to five synthesizers.

The purpose of the third step is to help members of the audience understand how exactly musicians' gestures impact the resulting sound, i.e. which modules they manipulate with each sensor. In other words, this step reveals the mappings used in the DMI. To that extent, virtual sensor extensions must be connected to the sound processing modules, to visualize the path from gestures to sound and the flows of data. In order to achieve this, 3D links are drawn between the virtual sensors and the 3D representations of the modules each time the physical sensors are manipulated to control parameters of the modules, i.e. each time the musician influences the instrument. They are not displayed permanently so that the virtual box is not visually overloaded. As depicted on Figure 8, links can be merged or split to simplify the visualization of one-to-many mappings [7], e.g. with one sensor controlling several sound modules. Finally, the links slowly fade away once a manipulation is over so that simultaneous gestures can be comprehended.

3. USING ROUAGES

When setting up *Rouages* for their own digital musical instrument, musicians need to follow three main steps.

3.1 Setting up the 3D rendering

Rouages allows musicians to precisely define several parameters that will be used to correctly render the virtual space so that it matches the physical space. The 3D rendering done using the Irrlicht[5] library is then adjusted by modifying the frustum of the virtual camera. First of all, screen dimensions and box dimensions, position and orientation need to be defined, together with the user head position that will define the sweet spot for a group of spectator. A spectator placed on that sweet spot will perceive a perfect alignment between the virtual and physical spaces, and so will spectators behind the spot within an angle, as described for another mixed-reality performance system in [17]. Display devices allowing for a other viewing angle are also being investigated as explained in section 5. In addition, stereoscopy can be enabled in order to improve the perception of the depth of 3D components. Furthermore, head position and box orientation can be acquired by connecting to a Virtual Reality Peripheral Network (VRPN) [6] server that may send tracking data from a large variety of 3 and 6 degrees of freedom tracking systems. The 3D view is then be modified accordingly dynamically.

3.2 Defining sensors extensions, sound modules and links

The second step consists in defining the modules that will represent the components of the DMI and connecting them to their associated visual components. Virtual sensor extensions can be created and placed individually but groups of sensors are also predefined for various commercial MIDI controllers. For example, Figure 4 shows sensors groups for the M-Audio Trigger Finger with 16 pads, 8 knobs and 4 faders, and for the Berhinger BCF2000 with 8 faders, 8 knobs and 16 buttons. Sensors can then be connected to software or hardware MIDI ports using the JACK Audio Connection Kit (JACK) multi-platform audio server [7], and associated with one or several MIDI messages. 3D representations of sound modules of the selected types (e.g. loop, synthesizer, playlist) may then be added inside the virtual box and connected to the modules. Once again, this is done with the JACK server, by creating audio input ports for each 3D object and connecting these ports to the corresponding audio output ports of the sound modules, and MIDI ports of the sensors. Finally, links between virtual sensor extensions and sound modules representations are defined to match the actual mappings of the DMI.

[5]http://irrlicht.sourceforge.net/

[6]http://www.cs.unc.edu/Research/vrpn/

[7]http://jackaudio.org

3.3 Choosing a skin

In addition to revealing musicians' impact and sometimes virtuosity, *Rouages* may also be used to illustrate the mood of an entire performance or of a particular track. Several skins can therefore be defined for each instrument, changing the appearance and animation of sensors extensions, representations of sound modules, links and box. Skins may follow our recommended behaviors for specific types of modules but they may also freely modify any parameter according to MIDI and audio input. For example, modifications of parameters such as color, translation, rotation, or any combinations of these parameters may be mapped to loudness variations. In addition, 3D animated models may be loaded. The animation is then mapped to value of the corresponding MIDI input or the loudness of the associated audio input, allowing for advanced 3D shape transformations. The third possibility is to use 2D animations in form of a set of PNG files, which are sequentially read as textures on 3D planes. Skins may be set for each 3D representation independently or for all representations of a type, e.g. all knobs, all loops. Two example skins for the same instrument are depicted on Figure 9.

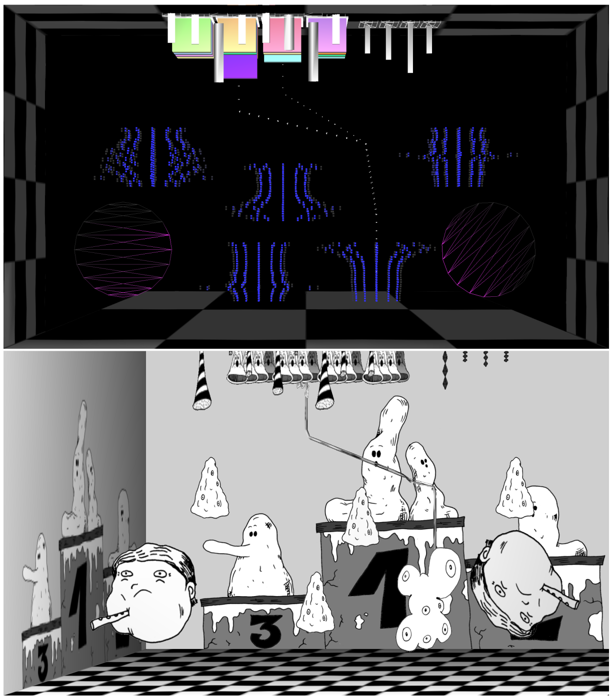

Figure 9: Skin examples. Top: 3D objects with shape/orientation animations, Bottom: 2D Animations

4. FEEDBACK

Informal feedback on our approach was obtained by sending a link to a video[8] of a performance with a DMI revealed by *Rouages* on private mailing-lists of the University of Bordeaux. The specific DMI is depicted on Figure 1. It is composed of three sound processes, two with one sound module (audio loop) and one with 5 modules (granular synthesizers). Additional audio effects modules such as compressors

[8]https://vimeo.com/63147015

are not displayed in order to simplify the representation, as their effect on the overall sound is constant. Each of the two loops can be started and stopped with two pads and the triggering offset can be controlled with a knob. The 5 synthesizer modules are played using various groups of pads and their parameters are all controlled with the same faders and knobs. We did not use a questionnaire but rather gathered the spontaneous comments of 10 people about the performance. Responses to the video ranged from positive to very enthusiastic, and they brought interesting comments. For example, one spectator (non-musician) said that:
"It is very meaningful. Drawing the links between the buttons and 3D objects is a big improvement for understanding. I guess that gears turn to show that a piece of music is being played, and that the pits allow for the activation of a particular sound".
This example illustrates that the spectator could understand both the structure of the instrument and the impact of musicians' gestures, thanks to the visualization provided by *Rouages*. A first suggested improvement was to provide a more detailed representation of loops, by displaying their waveforms or the played notes.. This comment relates to the different visualization possibilities that we describe in section 2.3, and will require more advanced audio analysis such as repetitions detection. Another recurrent suggestion is to expand the 3D visualization outside the box for a more spectacular effect. Although this first feedback is positive, a proper evaluation with both subjective and objective measurements needs to be conducted as explained in section 5.

5. CONCLUSION AND PERSPECTIVES

Rouages aims at improving the audience experience during electronic music performances by revealing the inner mechanisms of digital musical instruments. This is done by first amplifying musicians' gestures using virtual extensions of sensors, then describing how the sound is produced using 3D representations of the sound processes and finally showing the impact of musicians' gestures on these processes with dynamic graphical connections. Our approach is implemented for DMIs based on MIDI controllers with a mixed-reality display system and a software application.

Four main perspectives arise from our approach. The first pertains to the hardware side of our system. In order to allow for several correct viewing angles and to extend our current system to gestural controllers, technologies such as large multi-angle semi-transparent screens, or other multiple views display technologies will be evaluated. The second perspective relates to the classification and representation of sound processes and modules. Contrary to other classification approaches that define general properties [3] or mathematical representations [4] of DMIs, we need to define a taxonomy of commonly used sound modules. This taxonomy will range from generic modules to specialized ones, i.e. types of audio effects or synthesis techniques, in order to extend the defined behaviors for 3D representations and define adapted sound analysis techniques. The third perspective is the evaluation of the impact of the different parameters of our approach on the understanding of DMIs and more generally on the experience of the audience. These parameters are the representation level-of-detail, the physical-virtual collocation and the visualization of gestures-sound links. The final perspective is the extension to laptop orchestras. In this case, *Rouages* may enhance the understanding of the activity of each musician in the orchestra.

Rouages opens up new perspectives for improving audience experience with digital musical instruments. We hope that instrument makers and musicians will lean on this approach in their work. We also believe that *Rouages* could easily be transposed to other contexts such as artistic installations that involve digital interfaces.

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