The Saxelerophone: Demonstrating Gestural Virtuosity

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ABSTRACT

This paper presents the Saxelerophone, a hyper-instrument tracking data from a contact microphone and a 3-axis digital accelerometer, to enable the performer to create new interactive sounds while demonstrating gestural virtuosity. Saxophonists can move their instrument around in space relatively easily when playing. In fact, it is quite common to see this kind of demonstration in live performances. Although these *musical gestures* demonstrate a certain virtuosity on the part of the performer, they are not directly linked to sound production. Based on two important concepts of the field of Interactive Music System (IMS): the *spare bandwidth* and the *demonstration of virtuosity*, the objective of the Saxelerophone is to use the musical gestures of the performer to demonstrate a new form of gestural virtuosity and musicality, giving virtuoso performers extra power and finesse.

Author Keywords

Hyper-instrument, Saxophone, Musical gestures, Virtuosity

CCS Concepts

•**Applied computing** → **Sound and music computing;** Performing arts; •**Information systems** → *Music retrieval;*

1. INTRODUCTION

Virtuosity has the advantage of facilitating expression in computer music. It is therefore beneficial to take advantage of the virtuosity already developed by experienced players to develop new interfaces inspired by acoustic instruments [9]. On the one hand, taking advantage of virtuosity allows shortening the learning curve for the performer, as far as the acoustic part of the instrument is concerned, and on the other, it enables the reuse of virtuoso skills already acquired to develop new ones. That way, experienced players will find it easier to transform an instrument into a means of expression rather than an object in its own right. Virtuoso skills are also one of the main reasons for attending musical performances, since they enable us to demonstrate to an audience, either visually or acoustically, the learning and practice experience acquired by a musical performer [28]. For this reason, it is important to be able to demonstrate a certain *transparency* or *authenticity* in the relationship between the musical performer and the instrument [14], although it inevitably involves difficulty [19].

The Saxelerophone is an Interactive Music System (IMS) designed to take into account the *spare bandwidth* of the performer and the visual relationship between gesture and sound in live performance. The main objective is to improve the *demonstration of virtuosity*, which often tends to be misinterpreted by the public when it comes to new musical instruments [32]. By communicating new modes of sound embodiment while rethinking the existing relationship with the audience, the Saxelerophone aims at developing a new musical langage for demonstrating gestural virtuosity. On the one hand, it is a simple and flexible system composed of a contact microphone and a 3-axis digital accelerometer designed to be fitted to any reed instrument with a ligature. On the other hand, it is based on a complex gestural control of sound synthesis using robust machine learning methods for learning static regression mappings, enabling to build a new expressive and creative sound space for developing gestural virtuosity.

2. RELATED WORK

Extending the musical palette of an acoustic instrument is a solution that can be envisaged to demonstrate virtuosity. For instance, adding additional sensors to an existing instrument can enable new playing techniques or new musical nuances, bringing new ways of embodiment for the control of the sound by the virtuoso performer. The aim of these so-called "hyper-instruments" is to design augmented musical instruments "*using technology to give extra power and finesse to virtuosic performers*" [18]. Several hyper-instrument prototypes have been commercialized to date, such as the Yamaha Disklavier hyper-piano used in Jean-Claude Risset's pieces [27, 26], or the Selmer Varitone, a saxophone coupled with an octave divider extending electronics to reed players. Any type of instrument could be ideally augmented by adding sensors, however, this generally depends on the *spare bandwidth* of the musical performer. This refers to the fact that "*some players have spare bandwidth, some do not*" [7]. The trumpet has for example the advantage of being easily augmented, since it has both free physical space for the addition of sensors, and a large *spare bandwidth* for the performer to interact with the augmentations [31].

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In the current work, the main focus is on finding new ways to augment the saxophone using the gestural *spare bandwidth* of the performer. There have been many attempts to augment the saxophone so far, with the use of effects pedals on the saxophone being probably the most common. Adding a pedal of effects to the saxophone has the advantage of enabling performers to manipulate signal processing parameters in real time. Moreover, it is possible to connect the effects pedals to a software to, for example, control the electronic environment of a piece by exploring "*the linear relationship between gesture and electronic effect*" [24]. Although this type of augmentation contributes greatly to a new dimension of performance behavior, it nevertheless requires a great deal of attention on the part of the performer, and can thus reduce expressive possibilities.

Other attempts to augment the saxophone have completely abandoned the instrument's acoustic properties, or used them as a direct expressive control of the performer. In this regard, the Synthophone [1], considered to be the first MIDI saxophone, uses only the saxophone's tactile interface, sacrificing the acoustic sound. The bell of the saxophone is here used as an electronic box to develop new MIDI control possibilities. On the other hand, the Metasaxophone, developed by Burtner [4], has sought to preserve the instrument's acoustic properties by adding additional sensors. The sensors are here used to convert performance data into MIDI control messages. This has the advantage of enabling signal processing under the direct expressive control of the performer, using different types of relationship between the performer's actions and the generated sound.

A thorough knowledge of the intrinsic properties of the saxophone can also prove to be beneficial to the augmentation of the instrument. This can, for instance, make it possible to investigate and evaluate the effects of different body movements on the instrument's acoustic properties (i.e. breath pressure, lip pressure and key values), and use such movements as a testing ground for the creation of new electronic instruments inspired by the saxophone (e.g. Akai EWI 5000[2]; Roland AE-10 Aerophone[3]).

2.1 Gestural control of sound synthesis

Human body movements, or gestures, play an important role in saxophone playing. This is partly because saxophonists have *spare bandwidth* when it comes to moving their instrument in space. In fact, it is quite common to see this kind of demonstration in live performances. In the current project, the meaning of gesture refers to *musical gestures*, that is, "*human body movement that goes along with sounding music*" [16].

In the context of Human-Computer Interaction (HCI), various definitions and taxonomies of gestures have been proposed for the design of gesture controllers. The aim of gesture controllers is to recognize and interpret gestures to control a computer system. Common approach used in the musical domain has suggested dividing the subject of gestural control of sound synthesis in four parts with (i) gestural function, (ii) gestural acquisition, (iii) synthesis algorithms, and (iv) gesture-sound mapping [33].

[1] http://www.softwind.com/synthophone.html
[2] https://www.akaipro.com/ewi5000
[3] https://www.roland.com/us/products/aerophone_ae-10/

2.1.1 Gestural function

The lighter the saxophone, the freer the performer's *musical gestures*. The soprano saxophone being one of the smallest saxophones commonly used, it provides a good testing ground to create new interactive sounds while demonstrating a new form of gestural virtuosity. This gives virtuoso performers extra power and finesse. Most common *musical gestures* of the soprano saxophone's performer involve the neck and the arms, with adjustments of the pelvis and torso. Although highly individual in style and conduct, these gestures are rich and fairly consistent from one saxophone's performer to another. Figure 1 presents an overview of the variety of *musical gestures* of two soprano saxophone's performer.

Figure 1: Musical gestures of soprano saxophone's performers. Top: John Coltrane's improvisation on "My Favorite Things" (Comblain-La-Tour, 1965). Bottom: Kenny G's improvisation on "How Am I Supposed To Live Without You" (Grammy Awards, 1990).

To understand more the functional aspects of the *musical gestures* of the soprano saxophone's performer, we propose to refer to a recent taxonomy introduced by Jensenius [16], categorizing the *musical gestures* in four functional categories, namely:

1. **Sound-producing gestures:** gestures that produce sound during a musical performance.
2. **Communicative gestures:** gestures mainly used for communication, particularly between musicians in an ensemble (e.g. during an improvisation with several instrumentalists).
3. **Sound-facilitating gestures:** gestures that support the sound-producing gestures and which have also been referred to as *ancillary* [34], *expressive*, *accompanying* [8] or *non-obvious gestures* [33].
4. **Sound-accompanying gestures:** gestures that accompany sound in the sense that they are gestures in response to sound. Such gestures can also be referred to as *sound-tracing*, following the contours of sonic elements [13].

In the present project, the main focus is on the use of *sound-accompanying* gestures for their ability to either *trace* [13], or *mimic* [12] the *sound-producing* gestures. Recent works have used *sound-accompanying* gestures to involve rhythmic entrainment [21] or to influence musical perception [23]. Compared to *sound-facilitating* gestures, *sound-accompanying* gestures are not *ancillary* to sound, but rather used to "accompany" the characteristics of the sound. This raises the possibility of defining new methods to demonstrate a clearer visual relationship between gesture characteristics and sound control parameters, in order to demonstrate gestural virtuosity.

2.1.2 Gestural acquisition

According to Wanderley and Depalle [34], *musical gestures* can be acquired in three different ways, with:

1. **Direct gesture acquisition:** using sensor systems to capture basic physical gestures of a performer
2. **Indirect gesture acquisition:** capturing the structural properties of the sound produced by the instrument
3. **Physiological signal acquisition:** corresponding to the analysis of physiological signals (e.g. EEG)

With regard to the development of the saxophone as a hyper-instrument, most research work focused on the direct acquisition of *sound-producing* gestures from the acoustic instrument (e.g. Metasaxophone). Direct gesture acquisition enables capturing the various performer's actions with respect to the *sensitivity*, *stability*, and *repeatability* of the sensor [29]. In the current project, direct acquisition of *sound-producing* gestures is used for capturing the acoustic sound of the instrument, as well as direct acquisition of *sound-accompanying* gestures for capturing the orientation and changes in movement of the instrument. In addition, indirect gesture acquisition is used to provide additional information on the type of notes played on the saxophone. For this purpose, basic sound parameters (i.e. fundamental frequency) are extracted to give information on the sound's melodic profile.

2.1.3 Synthesis algorithm

Sound synthesis is associated with the study of sound representations for the implementation of sound generation devices [34]. Sound synthesis models can be classified in two categories, with (i) *physical models* useful for describing the mechanical and acoustic behavior of musical instruments, and (ii) *signal models* using mathematical structures for encoding the spectral and/or temporal properties of sounds. In the present project, signal modeling synthesis techniques are preferred for their flexibility in the choice of the relationships between musical gesture characteristics and sound control parameters (i.e. mapping). This gives the instrument designer/performer greater freedom to perform sound synthesis without explicit reference to the instrument producing the sound.

2.1.4 Gesture-sound mapping

According to Hunt et al. [15], the mapping of *musical gestures* to sound synthesis parameters can be designed based on four basic strategies, with relationships between control parameters ranging from *one-to-one*, *one-to-many*, *many-to-one* or *many-to-many*. In the field of IMS, several mapping strategies using machine learning have also been proposed for learning continuous non-linear correspondences between gesture features and sound synthesis parameters. In particular, robust methods using Artificial Neural Networks (ANNs) for learning static [20, 10] or temporal [11, 5] mappings strategies. In the present project, static gesture-sound mappings are investigated using regression methods, also known as *regression mappings* [11].

3. DESIGN AND IMPLEMENTATION

Based on the initial research work carried out on the saxophone and its *musical gestures*, we defined three main objectives for demonstrating gestural virtuosity with the Saxelerophone.

1. Audio sensing for providing information of the notes played on the instrument.
2. Gesture sensing for the prototyping of mappings strategies using machine learning.
3. Motion sensing for demonstrating gestural virtuosity.

Sensing objectives are achieved through the use of a contact microphone[4] and an ADXL337 3-axis digital accelerometer[5], positioned one on top of the other on the upper part of the saxophone's ligature. Sensing data is processed using the visual programming language Pure-Data[6] and run on a Bela board[7]. The code, design files and technical documentation to replicate the system are available at the following address: `https://github.com/joachimpoutaraud/saxelerophone`. An overview of the electronic components involved and their location on the soprano saxophone is presented in Figure 2.

Figure 2: The Saxelerophone. Left: Soprano saxophone (Selmer Super Action 80 Series II) with sensors on the mouthpiece connected to a Bela board. Right (top): ADXL337 3-axis digital accelerometer sensor positioned above the contact microphone. Right (bottom): Contact microphone based on piezo material positioned on the saxophone's ligature.

3.1 Audio sensing

The Saxelerophone uses audio sensing as a rich source of additional information about the sound's melodic profile of the performer. The use of a microphone as a sensor can enable interactive control dynamics of a sound synthesis algorithm by mapping the acoustic sound of the instrument to the control parameters [30]. This distinguishes the use of the microphone as an interactive sensor from basic effects.

[4] `https://www.farnell.com/datasheets/3123697.pdf`
[5] `https://www.analog.com/media/en/technical-documentation/data-sheets/adxl337.pdf`
[6] `https://puredata.info/`
[7] `https://bela.io/`

In the current project, a contact microphone made of piezoelectric ceramic material is used for sensing audio vibrations through contact with the saxophone's mouthpiece, and estimating the fundamental frequency of the notes played on the instrument. Figure 3 shows the piezo element used in this project.

Figure 3: Contact microphone made of a piezoelectric ceramic material. 27mm diameter with pre-soldered leads.

The estimation of the fundamental frequency is obtained by combining sinusoidal components extracted from the incoming sound waves of the saxophone. For that purpose, we used the *sigmund*[8] object for signal analysis in Pure Data, with sinusoidal components acquired by transforming the sound waves in the frequency domain using the Fast Fourier Transform (FFT). In order to work without audio dropouts, the block size of the FFT had to be increased to 512 samples. The estimated pitch can finally be used as a frequency carrier to synthesize new interactive sounds based on the notes played on the saxophone.

3.2 Gesture sensing

The Saxelerophone uses gesture sensing for the direct acquisition of *sound-accompanying* gestures of the performer. For this purpose, an accelerometer sensor is used to determine the orientation and changes in movement of the soprano saxophone. Accelerometer data enables to define a relationship between the *sound-accompanying* gestures and the sound synthesis parameters. Mapping of the gestures into sound synthesis parameters is performed using machine learning. A schematic representation of the Saxelerophone's mappings is presented in the diagram in Figure 4.

Machine learning provides statistical methods to extract meaningful information from the numerical gestures representations produced by the accelerometer sensor. Recent research in the international conference on New Interfaces for Musical Expression (NIME) notably used regression and classification algorithms to interrelate gesture and sound [6].

In the current project, we train a standard regression algorithm to build a new creative sound space for the performer. The algorithm is optimized using the Adam optimizer initialized with a default learning rate of 0.001 and a weight decay of 0.0001. Training of the algorithm is facilitated using an ANN framework for Pure Data called *neuralnet*[9]. This framework makes it possible to build a training set while interactively performing *sound-accompanying* gestures associated with sound synthesis parameters. The continuous numerical values predicted by the regression algorithm are then used to control four parameters of a sound synthesis algorithm. More specifically, the sound synthesis algorithm is used to modulate other synthesis parameters such as Pulse Width (PWM) and Amplitude (AM), where PWM controls the average power of a square wave modulated with an Low Frequency Oscillator (LFO), and AM controls the amplitude modulated with a sine wave oscillator. In addition, the sound synthesis algorithm enables the control of how long to delay the input signal, and how much output to send back into input (i.e. feedback). A schematic representation of the sound synthesis parameters involved in the Saxelerophone is presented in Figure 5.

[8]https://pd.iem.sh/objects/sigmund~

[9]https://github.com/alexdrymonitis/neuralnet

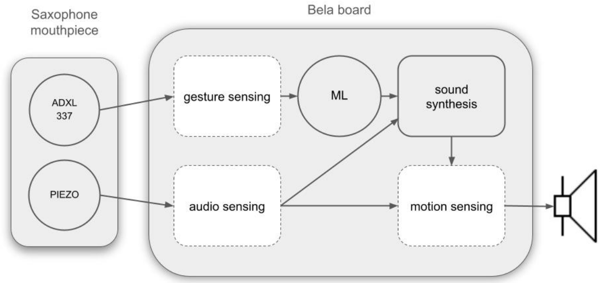

Figure 4: Saxelerophone's mappings. Left: Sensors of the Saxelerophone with an ADXL337 3-axis digital accelerometer and a contact microphone based on Piezo material. Right: Saxelerophone's mappings running on a Bela board with audio, gesture and motion sensing.

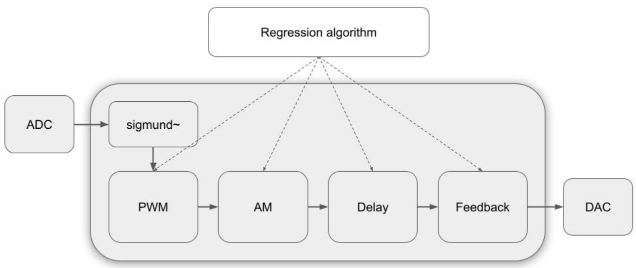

Figure 5: Sound synthesis parameters involved in the Saxelerophone. Pulse Width Modulation (PWM) controls the average power of a square wave modulated with an Low Frequency Oscillator (LFO), and Amplitude Modulation (AM) controls the amplitude modulated with a sine wave oscillator. Sound synthesis algorithm also enables the control of how long to delay the input signal, and how much output to send back into input (i.e. feedback).

3.3 Motion sensing

The Saxelerophone uses motion sensing to mix the acoustic sound of the saxophone with the synthesized sound generated by the sound synthesis algorithm. Integrate accelerometer data is here used to estimate velocity, which is then used as a means to control the volume of the acoustic and synthesized sounds. The volume of the acoustic sound being inversely proportional to the synthesized sound, this means that the higher the velocity, the more synthesized the sound, and vice versa. This allows the performer to play in two different ways, depending on the rate of change of his/her position with respect to time. As a result, motion sensing enables to demonstrate a clear relationship between *sound-accompanying* gestures of the performer and synthesized sound generation. This enables the performer to perform modulation synthesis by *tracing* sounds in space with the saxophone, as well as to demonstrate a certain gestural virtuosity while generating new interactive sounds.

4. EVALUATION

The evaluation of an IMS generally involves a variety of stakeholders that have different roles in the use, conception, perception or even commercialization of the system. This means taking into account different points of view, such as that of the *performer*, the *audience* or the *manufacturer* [22]. Given the scope of our project and the time available, we propose to focus on the *audience*'s perspective to assess how the audience understands how the Saxelerophone works, and the type of interaction it uses. Previous work considering the *audience*'s perspective has already developed a robust evaluation methodology to objectively measure communicative and cognitive issues related to Digital Musical Instruments (DMI) [1, 2].

4.1 A Preliminary Study

Based on previous evaluation methodologies, we conducted a preliminary study with an evaluation method composed of three steps, namely: audience profiling, data collection and data visualization. The preliminary study involved four participants who were asked to watch a video from a performance with the Saxelerophone and to fill up an online survey.

4.1.1 Audience profiling

In the first step, participants were asked to answer questions about personal topics such as their age, whether they play a musical instrument, and their relationship with technology and music. Results showed that 80% of the participants were between 25 and 31 years old, with all participants playing a musical instrument. Additionally, it was shown that 100% of the participants had a strong relationship with technology and music.

4.1.2 Data collection

In the second step, the objective was to evaluate how the audience understood how the Saxelerophone worked and the type of interaction it used. Participants were here asked to answer questions related to their comprehension of a video performance with the Saxelerophone. The questions were rated using a 5-points Likert scale [17] and based on the evaluation methodology developed by Bellotti et al. [3] and Barbosa [2] for assessing five aspects of a sensing system, namely: cause, effect, mapping, intention and error.

- Cause: How understandable are the gestures made by the performer for interacting with the Saxelerophone? (where 1 is “Did not understand” and 5 is “Completely understood”)
- Effect: Did the Saxelerophone provide enough audiovisual information for the audience to understand what is happening between the performer and it? (where 1 is “I do not agree” and 5 is “I completely agree”)
- Mapping: How clear is the relationship between the performer’s gestures and the resulting sound? (where 1 is “Did not understand” and 5 is “Completely understood”)
- Intention: How successful was the performer to express himself using the Saxelerophone? (where 1 is “Not successful” and 5 is “Very successful”)
- Error: Were the Saxelerophone’s errors perceived (e.g. technical problems and software bugs)? (where 1 is “Not perceivable” and 5 is “Very perceivable”)

The participants were also asked to classify the type of interaction provided by the Saxelerophone. For this purpose, the questions were also rated using a 5-points Likert scale but this time based on the taxonomy developed by Reeves et al. [25]:

- How would the participant classify the performer’s gestures for the functioning of the Saxelerophone?
- How would the participant classify the Saxelerophone’s response to the performer’s gestures?

4.1.3 Data visualization

In order to help visualizing and analyzing the results obtained on our evaluation methodology, a radar chart was used to plot the level of audience comprehension with regard to the Saxelerophone. Figure 6 presents the radar chart based on the average of the results of the survey, with values for each axis ranging from 1 to 5.

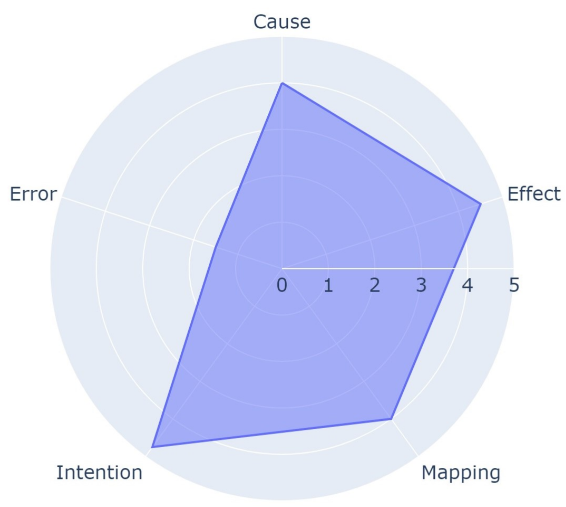

Figure 6: Radar chart of the level of audience comprehension with regard to the Saxelerophone.

The data visualization shows that the relationship between the performer’s gestures and the resulting sound (i.e. mapping) was well understood by the audience, with 25% of the participants rated 5, 50% rated 4, and 25% rated 3. In addition, 100% of participants rated 4 for understanding the gestures made by the performer when interacting with the Saxelerophone (i.e. the cause), with also 50% of participants rating 5 and 50% rating 4 for understanding what was happening between the performer and the Saxelerophone (i.e. the effect). This shows that the Saxelerophone can enable the performer to develop and demonstrate a certain gestural virtuosity. Furthermore, results based on Reeve’s taxonomy also confirmed our previous results. With 50% of the participants awarding a score of 4 and 50% a score of 3 for classifying the performer's gestures for the functioning of the Saxelerophone. In addition, 50% of the participants awarded a score of 5 and 50% a score 3 for classifying the Saxelerophone's response to the performer's gestures.

However, the results are here not compared with another IMS, nor with a different prototype version of the Saxelerophone. Such practice would have provided a more objective evaluation of the Saxelerophone and would have certainly resulted in a more accurate evaluation. Moreover, due to the scope of this work and the time available, it was not possible to evaluate the *performer*'s perspective of the IMS. This is mainly due to the fact that it was not possible to find virtuoso saxophonists available to evaluate the instrument in the time available. It is therefore possible that some additional information about the instrument has been lost.

Overall, this preliminary study provided a set of relevant results to assess the Saxelerophone's ability to demonstrate gestural virtuosity. The use of Belotti's and Reeve's evaluation methodology proved to be structured and practical methods for conducting such a study, although the lack of a comparison model and participants requires refinement of these results in the future.

5. CONCLUSIONS

Hyper-instruments have opened new possibilities for augmenting the musical palette of acoustic instruments. In this respect, improvements to the saxophone have led to new playing techniques and musical nuances, bringing new ways of embodying the virtuoso performer's control of sound. Current work with the Saxelerophone involves exploration of sound embodiment for demonstrating gestural virtuosity. By taking advantage of the virtuosity already developed by experienced saxophone performers, the objective of the Saxelerophone is to develop a new interactive system inspired by acoustic instruments, for developing a new relationship between gesture and sound. Using the gestural *spare bandwidth* of saxophone's performers, the Saxelerophone enables to perform modulation synthesis by tracing sounds in space. Gesture and motion sensing are here at the core of the instrument to demonstrate a clear relationship between the *sound-accompanying* gestures of the performer and the synthesized sound generation. This makes it possible to reinforce the live *demonstration of virtuosity*, which often tends to be misinterpreted by the audience in the field of IMS.

The Saxelerophone has made it possible to play in a way that is both visually and aurally engaging for the audience. With a unique and unexpected generation of sound synthesis based on automatic gesture learning, this IMS enables deeper audience engagement in live performance, as well as the possibility of developing a new musical language based on gestural virtuosity.

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