HypeSax: Saxophone acoustic augmentation

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ABSTRACT
New interfaces allow performers to access new possibilities for musical expression. Even though interfaces are often designed to be adaptable to different software, most of them rely on external speakers or similar transducers. This often results in disembodiment and acoustic disengagement from the interface; and, in the case of augmented instruments, from the instruments themselves. This paper describes a project in which a hybrid system allows an acoustic integration between the sound of acoustic saxophone and electronics.

Author Keywords
Hyperinstrument, Saxophone, Sensors, Gesture, Embodiment.

CCS Concepts
• **Hardware → Sensor devices and platforms**; • Human-centered computing → Gestural input; • Applied computing → Sound and music computing

1. INTRODUCTION
Performing with a musical instrument traditionally implies a strong physical connection between performative actions and sound through the interaction of two bodies: the body of the performer (possibly using an extension, e.g. mallet) and the body of the instrument. The action of strumming activates the vibration of the strings, blowing air into a flute at the correct angle produces a column of air that resonates in the body of the instrument, and hitting a drum also has a sounding result. All of these are examples of physical actions that connect the performer and the resulting sound, regardless of the quality of the sound or whether it is organized in any way. Regardless of the spectral structure (pitched or unpitched), the resulting sound corresponds to the action in a natural way: large/energetic movements result in loud sound while minimal/delicate movements produce an almost imperceptible sound.

Today the one-gesture-to-one-acoustic-event [22] paradigm has become blurred with the introduction of electronic systems and signal processing. In the case of augmented instruments, there are still actions that trigger an acoustic event, however these actions don't necessarily correspond gesturally with the output sound: pressing one button or activating a sensor can result in many different outcomes.

Another problem that arises with hyperinstruments is the disembodiment of the audio source, as the sound usually comes out of a speaker that is normally not part of the instrument, hence disengaging the acoustics from their body.

The HypeSax project addresses these issues with the goal of developing a hypersaxophone that reembodies electronics as part of the physicality of the instrument. There are many other issues that could be identified in the use of new technologies for musical creation in live contexts, especially from the point of view of the audience's perception. However, this paper will center on the design features that allow electronics to be inserted in the acoustic body of the saxophone.

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2. PRIOR ART
Many previous projects have served as inspirations for the design of the HypeSax. The precedents to this work have explored and developed technical accomplishments that have served as models for the design of the HypeSax. Projects such as the SABRe introduce a fully functional air pressure retrieval system [17] using a pipe that redirects air into a sensor, while García et al acquired blowing pressure profiles on a recorder by modifying the mouthpiece's body [5]. Various projects take advantage of push buttons and touch sensors as triggers, as well as gyroscopes and accelerometers [11]. Relatively few projects have focused specifically on saxophone augmentation. However, projects such as those directed by Burtner [2], Schiesser [19], Hong [7] [6], Portovedo [15], and Onozawa's work for Yamaha [14] [13] have served as inspiration in designing the HypeSax. Nevertheless, very few of those projects seek to achieve sound hybridization. The exception is Burtner's Metasax, which deals with feedback control using the mechanics and resonances of the saxophone body.

When it comes to augmenting the sound field of the instruments through combining instrumental acoustic sound and electronically generated sound, interesting research has been conducted at IRCAM, such as the IMAREV project [23] and Smart Intruments [24], Juan Arroyo's hybrid string instruments [8] and the Active Instruments [25] [10]. These projects approach instrumental augmentation as a fully integrated acoustic/electronic hybridization. Inspired by all of these projects, the HypeSax has the goal of achieving hybridization with a standalone system.

3. SYSTEM OVERVIEW
The HypeSax is a system designed to be an attachment that can be fitted on any ordinary alto saxophone. The system is modular and can work with some or all of its components attached to the saxophone. It consists of an Un-mute (3.1), Sensor-link (3.2), a customized mouthpiece (3.3), and keycaps with touch sensors and buttons (3.4) (see Figure 1). The system is capable of retrieving data using six touch sensors placed on the saxophone to work as additional keys, three push buttons used normally as triggers or switches, a special mouthpiece that captures air pressure data, gyroscope and accelerometer, a microphone to capture and process audio and a self-contained audio system (soundcard and speaker). The way in which all of these components work within the system is described in detail in the following sections.

3.1 Un-mute
Augmented instruments often work with a hemispherical speaker located near the performer, following Cook and Trueman's approach to "reorient the relationship between performer, sound source and listener" in electronic music performance [3]. However, a goal of this project is the integration of the electronics with the acoustics of the instrument. In order to achieve this, the HypeSax includes a speaker inside the saxophone to integrate the acoustic chamber of the instrument into the system. A 3D model of an enclosure was designed to

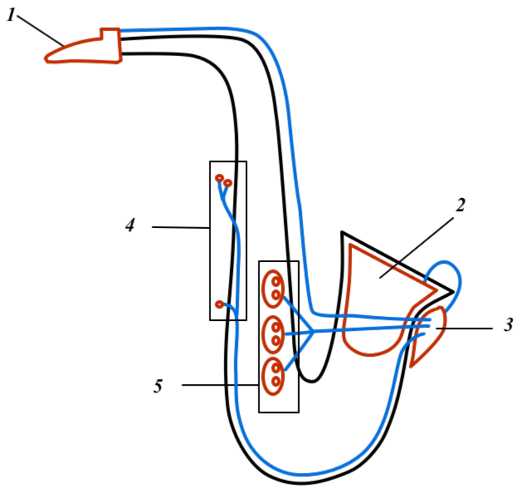

Figure 1. Modular components of the HypeSax. In red: mouthpiece (1), Un-mute (2), Sensor-link (3), new keys for thumbs (4) and new keys situated over custom-designed key caps (5). In blue: representation of the connecting wires.

hold the speaker and electronic components inside the bell of the saxophone, making the Un-mute the heart of the HypeSax. This mute-like enclosure and its components is called Un-mute. It is a device that, rather than muting the sound of the instrument, enriches the spectra by incorporating new components into the final sound.

The enclosure was designed to avoid negative effects on the air column inside the saxophone. A dip was included at the top of the Un-mute to allow air flow while playing in the low register of the instrument with most of the keys closed (see Figure 2). This design is somewhat effective, but it affects the air flow while playing the lowest note of the saxophone. This is due to the fact that the Un-mute is long enough to reach and partially block the opening of the low B♭ key when inserted in the bell, making it difficult to impossible to play the lowest note.

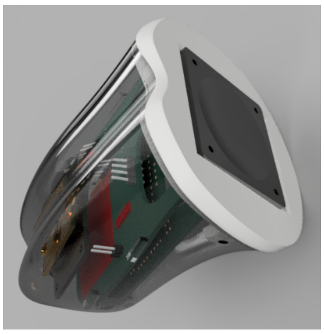

Figure 2. Un-mute for Alto Saxophone.

In the back of the enclosure there is an opening that allows for the free flow of air pressure produced by the back of the cone of the speaker, which is facing the front of the enclosure and out of the bell of the saxophone. The back opening is partially covered to stop moisture from entering the enclosure, potentially damaging the electronic components. Also, in the back, an electret microphone is positioned to capture audio. The close placement of the microphone and the speaker (about 7cm away from each other) is one of the reasons why the speaker faces forward and not directly into the opening of the saxophone. However, the back opening is big enough for the speaker's sound to travel back into the instrument in order to introduce new audio to the body of the saxophone. In the same way, the introduced audio is affected (filtered) by the resonance of the saxophone's acoustic chamber, allowing acoustical integration between acoustic sound and synthesis. Undoubtedly feedback can be present if there is a free signal flow and the levels are not calibrated. Nevertheless, feedback can become an interesting feature of the Un-mute which is discussed in section 4.1.3.

Without the Un-mute, the HypeSax cannot work, as it contains inside the most important electronic components of the HypeSax. The complete list of components includes two Teensy boards, an audio board adaptor for teensy, a mono 2.4W Class D audio amplifier PAM8302A, a 40Ohm 5W Speaker, an electret microphone, a capacitive touch sensor board MPR121, an accelerometer and gyroscope board GY-521 MPU6050, and two custom designed PCBs.

The system works with one Teensy LC board (slave) and a Teensy 3.2 board (master). The Teensy 3.2 is connected to the audio board adaptor. Its main function is to retrieve audio using an electret microphone, send the audio to a laptop via USB, and to receive audio signal that is outputted using the speaker mounted on the Un-mute. Currently the audio signal is being processed externally, but a goal is to develop the appropriate code to handle audio analysis and synthesis on board in future iterations. For this reason, a second microcontroller is used to collect data from the multiple sensors mounted on the saxophone. This configuration helps to minimize latency levels.

The slave microcontroller sends data to the master via serial communication. In order to achieve this, as well as to provide the appropriate connections for sensors and visual feedback (LEDs), two PCBs have been designed. This design fits inside the Un-mute and features a port which allows connection to the Sensor-link which is located outside the bell of the saxophone.

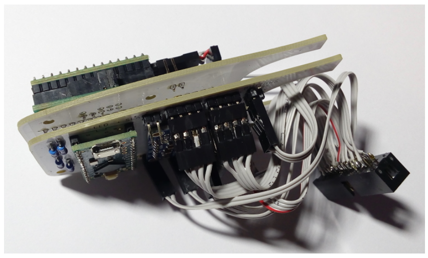

Figure 3. Un-mute's electronic components mounted on custom PCBs.

The HypeSax features only 6 touch keys (see section 3.4), but an Adafruit 12-key capacitive touch sensor board MPR121 is mounted on the PCB. The initial concept featured ten touch keys, but it became very difficult to incorporate all keys to the HypeSax for alto saxophone due to the limited space between the instrument's keys. However, even when only six keys are used, a 12-key breakout board was used in order to facilitate sharing code with future iterations of the HypeSax for bigger saxophones (tenor or baritone) which might feature more keys.

An accelerometer and gyroscope board GY-521 MPU6050 is also located inside the Un-mute, as the saxophone bell is possibly one of the best locations for it since it is right at the center of the instrument. This location helps with keeping track of any movement in x, y or z planes more accurately.

3.2 Sensor-link

As described in the previous section, the Un-mute holds the slave microcontroller that retrieves data from a variety of sensors. Some of these sensors are located in the mouthpiece, on saxophone keys and near the thumb rests. In order to connect those sensors to the slave microcontroller, the Sensor-link was developed, a custom PCB that features sensor inputs, a type B USB port, LED indicators for visual feedback, a gain knob and a standard 6.3mm jack to connect an expression pedal for gain control. The Sensor-link is the connector route where signal and data flows between the HypeSax and computer.

The implementation of the Sensor-link is arguably unnecessary, as the connecting ports could be located directly on the front face of the

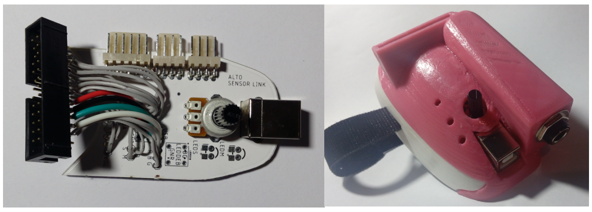

Figure 4. Sensor-link.

Un-mute. However, that design would make it difficult to fit all the components inside the Un-mute, particularly with the alto saxophone version. On the other hand, using some of the area of the Un-mute's front face to allocate sensor ports would result in less space for a speaker, which would have an impact on the audio capabilities of the system. For these reasons the Sensor-link is justifiable. In addition, it provides a better configuration of cable connection such as the USB and pedal jack facing down, preventing potential stress on the cables produced by gravity.

3.3 Mouthpiece

Acquiring data relating to the air flow going into the saxophone can be very difficult, but previous projects such as the SABRe [18] or the modified alto recorder mouthpiece by Garcia et al [5] demonstrated that using a tangential conduit can be effective to measure the variations in air pressure being blown into the instrument. A similar approach was used to develop a module for the HypeSax. A 3D model of an *Alto Saxophone Mouthpiece* designed by Thingiverse user Allanarps [21] obtained online was modified. The original design is based upon a Yamaha beginner mouthpiece, with similarities including bore length and shape, facing width, tip opening and basic length measurements, featuring a flat baffle and squared throat (bore). This model was modified to produce a new version that features a 1mm conduit that allows a portion of the air stream to be redirected into a barometer sensor, thus obtaining data about the air pressure without disturbing the air column inside the instrument. At the same time, this configuration provides a comfortable playing experience.

The adaptation keeps the basic shape of the interior with the same dimensions in the chamber of the mouthpiece, facing width and bore shape, which ensures that the air column running through the chamber behaves in the same manner as in the original design. The changes made to the design include a shorter tip opening of 1.8mm (original is 2mm) and a thicker beak that allocates a small conduit running through the body of the mouthpiece to an added section in the back in which a sensor is mounted to measure the air pressure. A minimal amount of material has been added to the top of the beak of the mouthpiece to accommodate the conduit. In total, 2mm of thickness has been added to the beak, within which a 1mm radius cylindrical opening is contained at the front/centre of the beak, where the structure is weaker because of its dimensions. Further back, the conduit opens more to fit the dimensions of the sensor at its back end (see Figure 5). There is also a small side canal that allows moisture and saliva to escape the system. This opening is usually blocked by the ligature during performance.

A BMP180 barometric sensor is mounted on the mouthpiece. Unlike most sensors designed to measure air pressure, the BMP180 doesn't feature a funnel-like structure to redirect the air into it, which becomes unnecessary with the conduit built into the mouthpiece 3D model. For this project, the GY68 breakout has been chosen because in this design the "hole" that captures the air in the sensor is situated close to one of its edges, which makes it convenient to introduce it in the body of the mouthpiece and reach the end of the conduit. Other breakout boards place the sensor on the center of the PCB, and the use of these boards would translate in carving into the model to reach the air conduit, which could compromise the structure of the mouthpiece. This breakout sends data via I²C. More details of this mouthpiece can be found in *A 3D printed hybrid saxophone mouthpiece for data collection* [16].

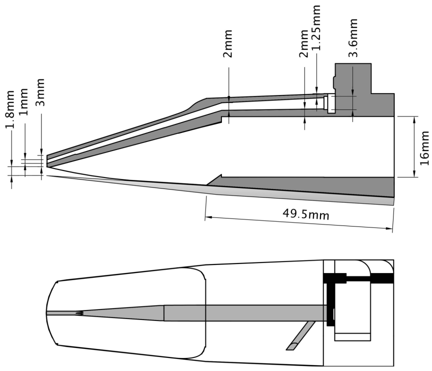

Figure 5. Interior of the mouthpiece. The top image shows a cross section of the mouthpiece where the chamber and conduit are shown in white. The bottom image shows the conduit and side canal in gray. The area designed to position the sensor breakout is colored in black.

3.4 New keys

Complex systems, such as the one implemented in the SABRe, monitor all keys to identify fingering by using Hall Effect sensors [17]. Such a design is highly effective but requires a complex setup process which makes the design inconvenient, which is possibly the reason why the commercial version of the SABRe (Multi-Sensor) doesn't include this fingering tracking system [26].

In the case of the HypeSax, easy setup and high compatibility with many saxophone models is a priority. To address this, a series of 3D models of saxophone key-caps were designed to allocate terminals coming from the MPR121 capacitive touch sensor board installed inside the Un-mute (see section 3.1). There are six terminals mounted on three key-caps which fit over the F, E and D keys. The 3D models are parametric and can be adapted to fit any size and configuration of saxophone keys.

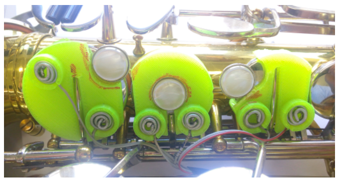

Figure 6. First iteration of 3D printed key-caps.

The position of the terminals mounted on the keycaps is close enough to the resting buttons of the keys, which allows for a comfortable experience while performing. With this configuration the performer can either close the keys by pressing the key buttons or by pressing on the touch pads. Depending on the shape of the performer's fingers and/or the angle of the finger in reference to the saxophone body, up to two touch pads can be touched by one finger at a time. The protuberances on the key-caps holding the terminals also help the player to avoid touching them by mistake. There is also a possibility of activating the touch sensors by only touching the terminals without pressing and closing the keys.

Three push buttons are included in the HypeSax design. Two of these buttons are mounted on the saxophone bellow the left thumb rest, and the third button is mounted next to the thumb hook to be easily accessible with the right thumb. Unlike the case of the terminals mounted on the saxophone keys, the thumbs interact with push buttons as the weight of the saxophone pushes against the thumbs, which produces unwanted interactions with touch sensors. This makes the mechanical system of the push buttons a more reliable approach.

4. SOFTWARE

The HypeSax has a USB port which allows communication with a computer or a MIDI device thanks to the high flexibility of Teensy boards. For this project, the slave board is set up as a Serial device since its only function is to gather information from the sensors, organize it and send it to the master board. The master board is set up to work as a Serial/MIDI/Audio device. With this configuration, the HypeSax is able to send MIDI messages for a full compatibility with MIDI devices or commercial software. It can work as an audio card to record and output audio (using the audio board adaptor), as well as send and receive audio signals through the USB port to a computer. It also communicates with a computer using the Serial protocol.

To take advantage of the latter aspect, a server application was developed in Max to receive, decode and organize the messages sent from the HypeSax. Once the communication is established, the application shows a visual representation of the sensors' activity. The user can then re-route the data using either MIDI, OSC, Serial or MAX's send/receive messages (when using the patch version of the application).

The potential of the HypeSax as a controller allows for adaptability for the creative needs of a composer or performer. However, this is the common approach of most hyperinstruments, where the hardware augmentations usually only work as controllers mounted on an instrument. This approach does not demerit a hyperinstrument, but at the same time there is not a real integration between the electronics and the instrument, as the synthesis (no matter how good it can be) remains as an addition output through an external source (speaker) rather than becoming integrated with the acoustics of the instrument.

Considering the idea of integration, the ideal goal for the HypeSax project is for it to be able to work as a standalone device without the need to communicate with a computer (in the same manner as devices like guitar pedals). However, at the moment the onboard software is being developed and it will take some time before the HypeSax can be fully independent. Nevertheless, computer software is being developed to achieve integration and will be featured in future releases.

4.1 Acoustic integration through use of software

As described in section 3.1, the Un-mute features a speaker that is mounted inside the bell of the saxophone. This allows for a new approach to hybridization of acoustic and electronic sound. Recent developments such as Juan Arroyo's hybrid string quartet [8] or the IMAREV project [23] have demonstrated the way in which active instruments allow for an interesting approach to sound treatment from an acoustical augmentation point of view. To achieve such augmentation, special software capable of real time audio analysis, sensor data analysis and audio processing has to be developed.

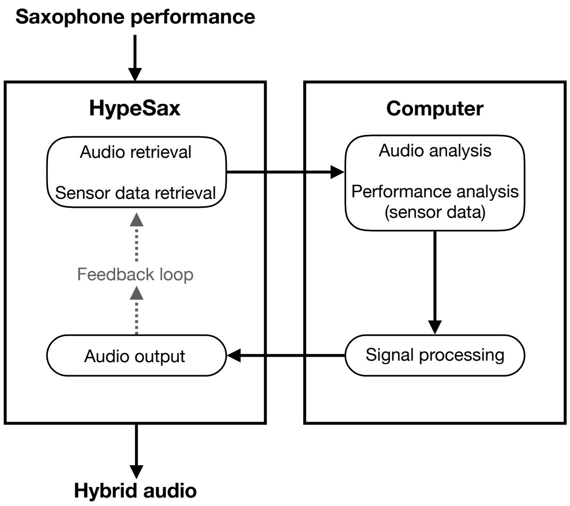

Figure 7. Data flow for acoustical integration

Any software developed to work with the HypeSax must follow the following data flow: First data is collected from the performance via HypeSax sensors. This data is sent to the computer using the built-in USB port. Software analyzes audio and sensor data to process signal. Signal is sent back to the HypeSax and inserted in the body of the saxophone to achieve audio hybridization. In some cases, the software might allow feedback for a special audio treatment (see Figure 7).

Currently experimental software seeking to achieve hybrid sound and musical expressivity through gestural embodiment is being developed. In the following sections some examples of experimental software are discussed in detail.

4.1.1 Experiments with sound morphology manipulation

Timbre manipulation is one of the most exciting possibilities of audio treatment using new software. In the case of the HypeSax software, two approaches to sound morphology manipulation have been explored, one in the time domain and the other in the frequency domain.

To work in the time-domain, a Max patch records audio continuously in a ten-minute long buffer, which rolls over to continue recording indefinitely. A timer keeps track of elapsed time to be able to match the exact moment of any event with the audio being recorded. Previous to the performance, a calibration process of the gyroscope is necessary. This process consists of holding the saxophone in a natural playing position and pressing the calibration button on the Max patch. This sets the X, Y and Z axes to 0. Using the touch pads or the push buttons (this can be set up according to the preference of the performer or composer) the performer triggers a granulation relative to the time position of the buffer at that moment, which creates the effect of freezing the pitch. This effect has an envelope which varies in reference to the Y axis of the saxophone position while performing (see figure 8). If $Y > 0$ (lifting the bell) a fast attack and release operate when activating or deactivating the granulation. If $Y < 0$ the attack and release are slow. The gain of the granular synthesis is controlled by the air pressure measured by the mouthpiece, effectively having a similar variation to that of the acoustic saxophone sound. There is no real-time unprocessed signal being outputted to avoid feedback. In this way, the performer can introduce a second voice whose envelope can be manipulated to create a complex timbre or multiphonic effect when mixed with the acoustic sound. The performer can then create different effects overlapping pitch changes of the acoustic sound with the granular synthesis, creating microtonal effects, beating, multiphonics, etc., which can be manipulated over time.

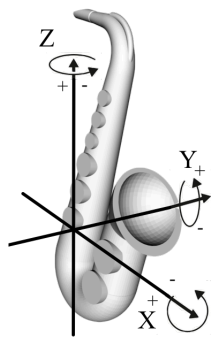

Figure 8. X, Y and Z Axes of the HypeSax's gyroscope in reference to the saxophone's natural performing position

In the frequency-domain, the authors have the intention to transform the timbre of the saxophone by reinforcing the energy of selected overtones in order to emulate the unique timbres of other instruments. A Max patch analyses the audio to obtain the fundamental frequency. It also tracks the relative energy of the overtones in the harmonic series. Then, based on data obtained from previous analysis of other instruments (i.e., a clarinet) playing the same pitch, the patch makes a comparison of the energy of each of the first 15 overtones in the harmonic series of the saxophone and the analyzed instrument. Then, using an active multi-band filter with a high Q on each of the 15 overtones, the software reintroduces the original audio which has now been filtered to add more energy or no energy on the overtones, simulating the timbre of the analyzed instrument. This approach is effective, but further work on the patch is necessary as the current version is resource-intensive and produces constant crashes.

A second approach with similar results was also explored. In this case, the patch only tracks the fundamental frequency. Then the software uses data from previous analysis and comparisons of saxophone recordings and other instruments. In this case, the data only tells the software how much gain it needs to control the components of an additive synthesizer. Finally, the synthesized sound is introduced into the saxophone.

The quality of audio resulted from the first approach is better, but unreliable. Perceptively, the second approach is good enough to achieve the effect of timbre modification. However, the system is limited to the power of the audio system, which means that manipulating the timbre is only possible when performing with a dynamic range between ***ppp*** and ***mf***. Louder dynamics are possible but not completely effective as the saxophone can overpower the capabilities of the audio system. Also, timbre transformation is not very convincing when using the models of instruments with defined envelopes such as plucked strings, piano, percussion, etc. Using models of fiddle instruments, woodwind, brass and particularly double reed instruments and clarinet (possibly due to its unusual harmonic series) are very convincing.

4.1.2 Gestural-instrumental-technique: an approach to instrumental-gesture embodiment.

Every instrument or family of instruments has a characteristic set of performing techniques. Strings, for instance, can be plucked and bowed, however it is not common to bow some instruments such a harp (although it is possible using extended techniques). The difference between bowed and plucked techniques is mainly the envelope control. A high degree of envelop control is possible to achieve with woodwind instruments thanks to a combination of articulation and breath control.

Some techniques are more specific to an instrument. The ricochet is a technique unique to fiddle instruments, which again can be imitated using extended techniques with other string instruments. Nevertheless, the ricochet is impossible to achieve with woodwind instruments due to its characteristic echo-like fast series of attacks with a loss of energy, which cannot be replicated with articulation and breath control.

These kinds of instrumental techniques require a specific physical gesture. In the case of the ricochet, the physical gesture is a strike on the string followed by natural bouncing of the bow over the string. This is what we call gestural-instrumental-technique, a physical action that results in a specific instrumental technique. Some gestural-instrumental-techniques are transferable between instruments. The ricochet for instance can be achieved on the piano using a mallet directly on the strings, but no similar action can be performed with brass instruments to achieve a similar effect.

The HypeSax can potentially extend the limits of the saxophone gestural-instrumental-techniques, through the addition of techniques previously unique to other instruments. Using a mix of gesture recognition techniques and audio analysis we have been able to bring ricochet, sul pont/sul tasto, and string subharmonic techniques to the saxophone.

The ricochet requires the use of two sensors and slap tongue. The first step is to perform a slap tongue which is monitored by the mouthpiece's air pressure sensor. The air pressure changes produced by this technique follow a distinctive curve (see figure 10) which begins with a negative reading resulting from sucking and pulling the reed, followed by a rapid increase of pressure and a quick release back to negative, and then zero pressure. The performer must also press quickly two buttons or touch pads (configurable by the user). The order or events must be then as follows: 1) slap tongue, 2) trigger 1, and 3) trigger 2. If these three events occur in a lapse of less than 500 milliseconds, the software triggers a short loop of 200ms since the last peak (of the last 500ms) with a decaying envelope of 1.5 seconds. The result outputted through the HypeSax into the saxophone resembles that of the string ricochet.

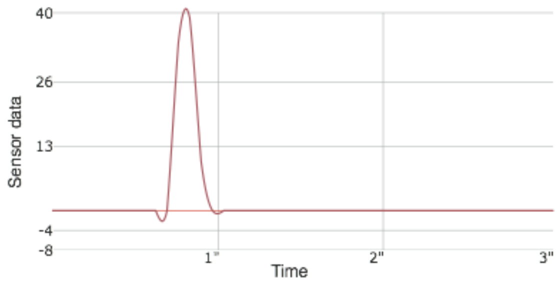

Figure 10. Typical data curve of air pressure changes in slap tongue technique

Sul ponticello string technique is achieved by placing the string exciter (bow in the case of fiddles, plectrum or fingers in plucked string instruments) close to one of the ends of the string, while for the sul tasto technique the exciter is placed near the center of the length of the string. The sounding result is an accentuation on the higher harmonics or the lower ones. In the case of the cello, the bow is typically taken down to the lower part of the string, near the bridge for sul pont sound, and up for sul tasto. Following this model, in the HypeSax, the user activates the touch pads in a consecutive way going from the highest to the lowest (top F-key to low D-key touch pads) imitating the cello sul pont action, or in the opposite direction for sul tasto, in a sweeping movement, usually with one finger. When the software detects this physical gesture, the incoming audio signal is filtered (low or high pass according to the gesture) and reintroduces the filtered sound into the system.

The string subharmonic technique as utilized in works such as George Crumb's *Black Angels* (called pedal tones) [4] or the work of Mary Kimura [9] is useful in extending the range of instruments. In the specific case of bowed strings, three factors seem to be the most crucial: Bow pressure, bow speed, and bow position. Considering this, the HypeSax software looks for a similar combination of three factors: the mouthpiece must read a data of high pressure (imitating bow pressure), the pressure must remain somewhat constant for two seconds (imitating bow speed), and the saxophone must be tilted over the X axis to read negative numbers (see figure 8), taking the bell to the right and mouth piece to the left in a counter-clockwise direction from the perspective of the performer. During these events, the fundamental frequency is being tracked. When the three factors are in play, the first subharmonic (an 8ve lower) is introduced. Augmenting the inclination on the X axis produces a second subharmonic (8ve + p5) and replaces the first subharmonic. The synthesis is constructed with sine waves using the frequency of the interval of the subharmonic (an 8ve or 8ve+p5 lower) mixed with a real time transposition of the original sound, filtered with a high Q over the fundamental frequency of the transposed sound, which adds a natural aspect to the synthesis.

4.1.3 Acoustic electronics: feedback as a musical element

Introducing audio in the body of the saxophone using the HypeSax system can produce unwanted feedback due to the closeness between the microphone and the speaker. However, it is very exciting to discover that the feedback can be controlled by the mechanics of the saxophone. Opening and closing keys has the effect of changing the length of the tube and the resonance of the internal space, which has a direct effect on the feedback, a phenomenon previously explored in composition by

Burtner [1] and further explored by Snyder et al [20]. The pitch of the feedback can be controlled with the saxophone keys, as well as by introducing air pressure or playing pitches with the saxophone. Also, by changing the gain using the built-in pedal effect jack, the introduction or amount of feedback can be controlled. This is a remarkable hybridization between electronic sound and mechanical control which is worth exploring further.

5. EVALUATION AND LIMITATIONS

The HypeSax as a controller works without issues at the moment. However, we are aware of potential for improvement to the design, especially from the technical point of view, through re-testing and curating the best sensor and electronic components to achieve optimization. Nevertheless, the ergonomics of the design do not interfere with the normal instrumental techniques.

In the specific case of the alto HypeSax, a major downside is the loss of the lowest note the saxophone's range, due to the disturbance of the air column by the Un-mute. Another issue is the fact that the HypeSax cannot equal the volume of the saxophone, meaning that hybridization can only be achieved at restrained dynamic levels.

Further evaluation is required to assess the software in musical contexts.

6. CONCLUSIONS AND FUTURE WORK

The HypeSax, in its developing phase, allows the user to aproach acoustical and musical gesture in a unique way. Although further research and development is necessary, the potential to transform timbre and to enrich the capabilities of the saxophone through adapting techniques borrowed from other instruments are possibly the two most important affordances of the project. From the perspective of the composer and performer, the openness of software integration (custom or commercial) using the server or MIDI is a strong point in favor of the HypeSax, and it is the intention of the authors to maintain this aspect in further iterations of the HypeSax.

The next two goals of the project are to achieve complete independence from the computer, and to develop a more powerful audio system. The Un-mute can potentially be adapted to fit in different instruments, and its acoustic impact will depend on many aspects including the shape of the instrument, the acoustic response of the speaker, the position of the speaker (facing inwards or outwards from the body of the instrument), use of multiple speakers, audio capture system and processing, microphones, etc. Further study of its effect on the resulting sound of any adaptation is necessary, and at the moment the concept resembles an expansion of the active mute designed by Meurisse et al. [12]

Future iterations of the HypeSax will include new designs for other instruments in the saxophone family. Most importantly, future work will focus on refining the built-in audio system and ergonomic aspect of the design, as it is the wish of the authors that the HypeSax be highly efficient and functional without negatively affecting the performer/instrument relationship or the capabilities of the instrument, truly providing a comfortable and effective hybrid instrument experience.

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