PRIME Gesture Recognition

New paradigms for the interaction between Paetzold recorder players and machines in live electronic music

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PRIME Gesture Recognition is a research project realized at HEMU (Haute École de Musique Vaud Valais Fribourg) that deals with gesture-tracking as applied to Paetzold recorders. Simone Conforti and Angelika Güsewell describe the project, and collaboration that ensued with six young composers and the PRIME Recorder Ensemble.

CONTEXT OF THE PROJECT

The PRIME Project started in 2006 as a DORE[1]-funded research project aimed at developing and propagating an exhaustive online sound catalogue for the Paetzold recorder[2] (www.primeresearch.ch). During the last two years, a follow-up project entitled PRIME Gesture Recognition[3] investigated the possibilities of following the gestures made when performing on this particular family of square recorders.

Why a research project on the Paetzold recorder? First, if we consider the Paetzold recorder's relative newness when compared to the long history of classical instruments, it seems crucial to work on compositional aspects: even if there is already a wide repertoire for square recorders thanks to the efforts of several important players[4], a lot has still to be explored in the realms of both acoustic performance and electronic treatment. Secondly, like any other musical instrument, the Paetzold recorder has its own unique characteristics that can suggest certain musical directions and guide compositional research.

On the one hand, the unusual construction of the instrument allows for a rich palette of breathy tones, percussive sounds, noisy sounds, and a huge range of multiphonics that are far easier to play with lower breath pressure than on Baroque recorders. This extremely broad spectrum of sounds, together with the Paetzold recorder's many possibilities in terms of extended techniques, makes it a very interesting instrument for performing contemporary music. On the other hand, the Paetzold has specific deficiencies that can be partially overcome through the intervention of technology. For example, the Paetzold's lack of stability in tuning depends on the dynamics played — the stronger the performer blows, the more the pitch rises (a phenomenon common to all recorders, that limits the dynamic range when they are played in a traditional way). However, this can be improved via an adaptive dynamics extender[5].

The present project is one of several in the Swiss music research community that are engaged in a similar field, such as The Recorder Map (cf. reference 7), a research project of the Basel School of Music, and the SABRe Sensor Augmented Bass Clarinet (cf. references 5, 6), a research project of the Institute for Computer Music and Sound Technology of the Zurich University of the Arts.

DEFINITION OF THE FIELD OF RESEARCH

Music performances are the result of a range of interacting factors, some of which are linked to the personal attitudes of a performer — each musician reacts differently to specific stimuli and has his or her own individual approach to their instrument — while others are related to the movements or gestures required to express the composer's musical thought or to adhere to a specific musical style. Every time a musician intends to produce a specific sound or convey a musical intention, she or he needs to perform specific psychophysical actions or movements.

These movements can be either physical (i.e. bodily and therefore visible) or mental (i.e. imaginary and invisible). Both categories are subsumed under the term "gesture", which, in a musical context, is generally defined as "any human action used to generate sound"[6].

Bodily actions or movements can be very evident (i.e. fingers moving to act on the keys) or almost completely invisible (i.e. different manners of inhaling before emitting a sound, or tiny bodily movements that vary according to the musical nuances required). Computers and sensors are thus needed to "follow" or "track" the many movements and gestures involved (whether clearly visible or not) when a musician achieves a specific sound or musical expression. Such "gesture-tracking" has been defined in different ways by the electronic music community, depending on the scope of the tracking and the performer's actions involved. However, two main categories can be distinguished:

1. Gesture-tracking based on individual, personal bodily movements;
2. Gesture-tracking based on specific movements correlated to the musical interface (the instrument).

The research conducted within the scope of Prime Gesture only concerned the second category, that is, tracking the physical events that occur during a musical performance on a Paetzold that are not related to the musician's individual physique, attitudes or technique (and would therefore be different from one player to another), and that can be considered as meaningful and relevant to use with electronics, and with respect to the three desired fields of application, namely:

— achieving a better understanding of what happens during musical performance, in order to train musicians more systematically on the basis of objective results;
— extending the instruments' capabilities and features;
— enabling a new type of performance in which the body becomes part of an extended interpretation of a musical event.

Against the background of these fields of application, the replicability of the data tracked seemed to be the key criterion: a certain similitude or predictability of the gestures is crucial to obtaining musical results which can be controlled and thus used by composers aiming at more or less similar results for different performances of their pieces. Because the fingers and the mouth are the only standard parts of the body that a recorder player uses, only movements related to fingering and blowing were considered.

Thanks to this awareness, it was possible to take the next step by selecting the most appropriate technologies to follow the gestures in question. A wide range of studies has been carried out in the field of gesture-tracking since the 1980s, especially concerning augmented instruments[7]. Famous examples are the MIDI Flute developed at Ircam in the 1980s, the Disklavier piano developed by Yamaha in 1987, the IR Violin developed by Peter Beyls in 1990, and Caesar Villaviciencio's augmented Paetzold in 2000 (cf. reference 2). Many technologies and approaches were developed within the scope of these and similar research projects, from cameras to gloves, sensor suits and applied sensors.

The problem is that many of these devices, such as cameras or sensor suits, while being able to record bodily movements precisely, are not precise enough for gestures directly connected to the instrument (i.e. systems for motion capture vs. specific sensors). However, because it is these tiny, often unseen movements that are crucial within the scope of the present research (in the case of the Paetzold recorded there are none of the evident, large bodily gestures that can be observed in string players or percussionists, for example), we started with a close analysis of the playing action from the instrument's point of view. This was intended to allow us to select (or develop) and implement a technology that would not only be closely connected to musical "objective events" such as notes and dynamics, but would also be able to track as much gestural information as possible from the instrument and its "traditional excitation", in particular the position and movement of the keys and the air flow within the instrument.

PROCEDURE — THE TECHNOLOGY DEVELOPED

This approach led us to the development of a specific class of music instrument named hyperinstruments[8], i.e. instruments whose capabilities are extended by means of electronic interaction. Such extensions permit the coexistence of an acoustic and an electronic instrument, the two sharing the same common identity, but preserving and combining their specific characteristics and advantages.

As already mentioned, many technologies had been developed within the scope of former projects that are able to track body movements, and were easily available. However, after a test period, necessary to explore existing technologies, it became apparent that none of them fulfilled our requirements in terms of reliability, precision and stability when they were used to follow fingering and blowing events.

A new hardware system was therefore developed, based on the I-CubeX (cf. reference 8) sensor interface. This is one of the most reliable on the market in terms of bit depth and technical support, and is also one of the smallest (which is a key aspect in this project). Another advantage of the I-CubeX interface is that it has numerous features for software communication, whether it is used with its standalone application or in combination with Max MSP (cf. reference 9), which was the solution adopted here.

In the previous sections, we noted that we decided to focus on the musical actions of the fingers and mouth of recorder players because we can be sure of the reliability and replicability of the data derived from tracking these actions. It was therefore necessary to implement two types of sensors: (a) air pressure sensors to monitor the air flow; and (b) sensors related to the instrument's keys to measure either the movement and pressure of the fingers, or the distance between the keys and the body of the instrument.

A piezoresistive air pressure sensor[9] was selected to monitor the airflow for two reasons: first, whereas microphones typically have a very poor low frequency response, such sensors offer a good stability when measuring both constant and slowly varying breath pressure (cf. references 3, 4); and secondly, it is possible to retrieve blowing information before the sound leaves the instrument by adopting a solution that

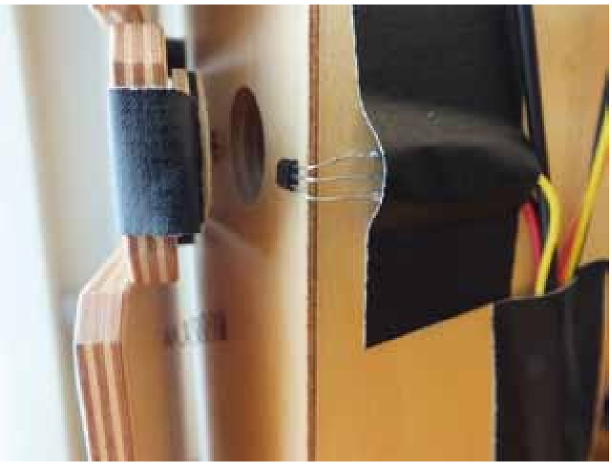

Figure 1: This picture shows a magnet which is under the tape on the key, and the magnetic field sensor on the instrument's body. © Simone Conforti

enables us to plug the air sensor directly into the drip cup (a solution designed and developed with the help of the current Paetzold recorder builder Jo Kunath).

With respect to key sensors, a solution measuring the distance between the instrument's body and the keys was required, as this parameter corresponds to what a musician playing the Paetzold recorder mainly focuses on: the movement, speed and virtuosity of his or her fingers (and not the pressure of fingers on the keys, as this has no influence on the sound). Two options were considered: magnetic field sensors able to recognize the distance between magnets fixed on the keys and the sensors fixed on the instrument's body, and bend sensors based on a piezoresistive surface that reacts to changes of flexion. A solution using custom-made magnetic field sensors proved to be more stable and was therefore adopted. Because the space between the completely closed keys and the body of the instrument (less than 1 cm) was too small for the I-CubeX magnet sensor, a Honeywell SS49E sensor was used within the I-CubeX sensor interface, and proved to be optimal in terms of compatibility, precision and costs (Fig. 1).

This hardware system was controlled via Max MSP from Cycling '74, which is the platform used to access the data and to manage it through a library provided by the I-CubeX. Through this library, the sensitivity of the sensor could be managed in order to access more detailed information. The overall sensitivity was increased so that it could also follow very subtle changes. In parallel with this, specific tools were developed to map the sensors, such as an auto-calibration algorithm that simplifies the adaptation to the instrument's physical characteristics in order to obtain a similar output for all the tracked instrument features[10].

Thanks to this auto-calibration software, the solution developed (Fig. 2) is easily applicable to any instrument and recorder player. All one has to do is to switch on the auto-calibration software and ask the musician to play a scale in which

Figure 2: Paetzold recorder fully equipped with sensors. © Simone Conforti

he or she blows with different dynamics. After this short pretest, the ranges are saved in the Max patch and ready to be used.

Even though data coming from the sensors and the live electronics processes can be managed on the same computer, we nevertheless developed a software to handle the sensors in a separate environment because for practical reasons the whole system often runs on two different machines. For example, in a concert situation it may be necessary to have a computer close to the instruments in order to plug in the sensor interface and control the hardware section more easily, while another computer is placed at the console where the electronic music performer remains during the concert. The system was developed using a modular approach with such needs in mind, as this gives one the possibility of choosing which solution is the better at any given time[11].

After rescaling, incoming data is treated by three different models for sensor detection that were developed within the scope of the project: “switch”, which can be used to trigger any kind of software elements that could be switched; “speed”, which determines how many movements happen within a specific time frame; and “gain”, which stands for the real excursion of a sensor. Of course, these three detectors are not freely usable in any case or with any kind of sensor. However, by skillfully combining them, it is possible to track any kind of relevant information derived from the playing action. For example, they can be used to track the keys, as happens in wind controllers[12], and they can deduce musical notes from the standard fingerings. Finally, a graphic interface allows for a rapid and fast check of what is happening with the sensors.

MUSICAL INTERACTION

As mentioned above, the artistic aim of the project was to develop electronic musical resources for creating new compositions, implementing and taking advantage of the new interaction possibilities between gestures and machines. For this reason, commissioning new pieces for the Prime Recorder Ensemble[13] was an integral part of the project. It was made possible thanks to a collaboration between the HEMU, the Master students in composition at the University of the Arts Bremen and two other composers, one from the Haute École de Musique de Genève and the other from the Zurich University of the Arts. This group of composers attended workshops on the peculiarities of the instrument and about interoperability between sensors and machines, and then wrote five pieces[14] that were premiered in Bremen and Berlin in Spring 2014.

A full article on each composition would be needed in order to describe each of them in detail. However, a few aspects of the pieces written by the young composers involved in the project will be discussed here in order to give some insight into the wide range of possible applications of the controllers we developed.

The first and easiest example affects the pedal control that is often employed in live electronics as a step controller for the events list; it was here substituted with a trigger that can be implemented via the key’s sensors or via a tactile (pressure) sensor placed on the body of the instrument. Both solutions were applied by the composers involved: for one of them, the standard key sensors were the right solution, as they can be seen as the deepest integration between musical gesture and machine control; for others, the tactile sensor was the preferred choice, which allows for more ergonomics than the use of the pedal.

This first example can be interpreted as a combination of musical writing and electronic interaction: if we imagine that specific written elements (notes in the score, for example) not only define a musical parameter (pitch, for example), but also fulfill a function of interactive control, it is easy to understand how interaction becomes a new paradigm and how a direct relationship between writing music and the remote control of the electronics is established.

As already mentioned, the keys’ interaction can even be extended. Using position detection, changes in key position can be used to elicit dynamic variations. In fact, any continuous modulation in terms of density, and any variation of a parameter, can be related directly to variations of the keys’ position. The fact that there is quite a large space between the Paetzold recorder’s keys and the instrument allows them to be used as faders of a MIDI controller, something which is impossible on every other wind instrument. Indeed, the variation is very easy to control and to map. Many intermediate positions and a full range of movements can be defined, thus allowing for a very good performance in terms of remote control. And this, in turn, enables one to deal with traditional musical elements (e.g. notes, sequences or specific techniques) and to use them to extract data that can then be applied to control certain processes or to use the instrument as a new mechanical interface.

Two music examples can help to clarify these principles. In the first case, the tremolo technique is used to control spatial movements: the faster the tremolo, the faster the speed of the sound’s movement around the audience (Fig. 3). In the second case, the player can gradually change the center frequency of each filter of a filter bank by pressing a specific key. The result is a modulation of the noisy sound produced by the player himself.

Beyond such applications, the augmented instrument approach is an invitation to more sophisticated relationships in which the results of the electronic elaboration can also be produced by relational feedback between the musicians and their actions (i.e. the direct control of the musical action by the player). In this approach, the instrumental players are part of the final result of the whole live electronic process and no longer remain uninvolved as soon as the sound has been captured by the microphone.

A deeper investigation into the information that can be gathered from the keys shows that the speed or the density of movements can also be a resource. Indeed, in some of the pieces, the relationship between the quantity of movements

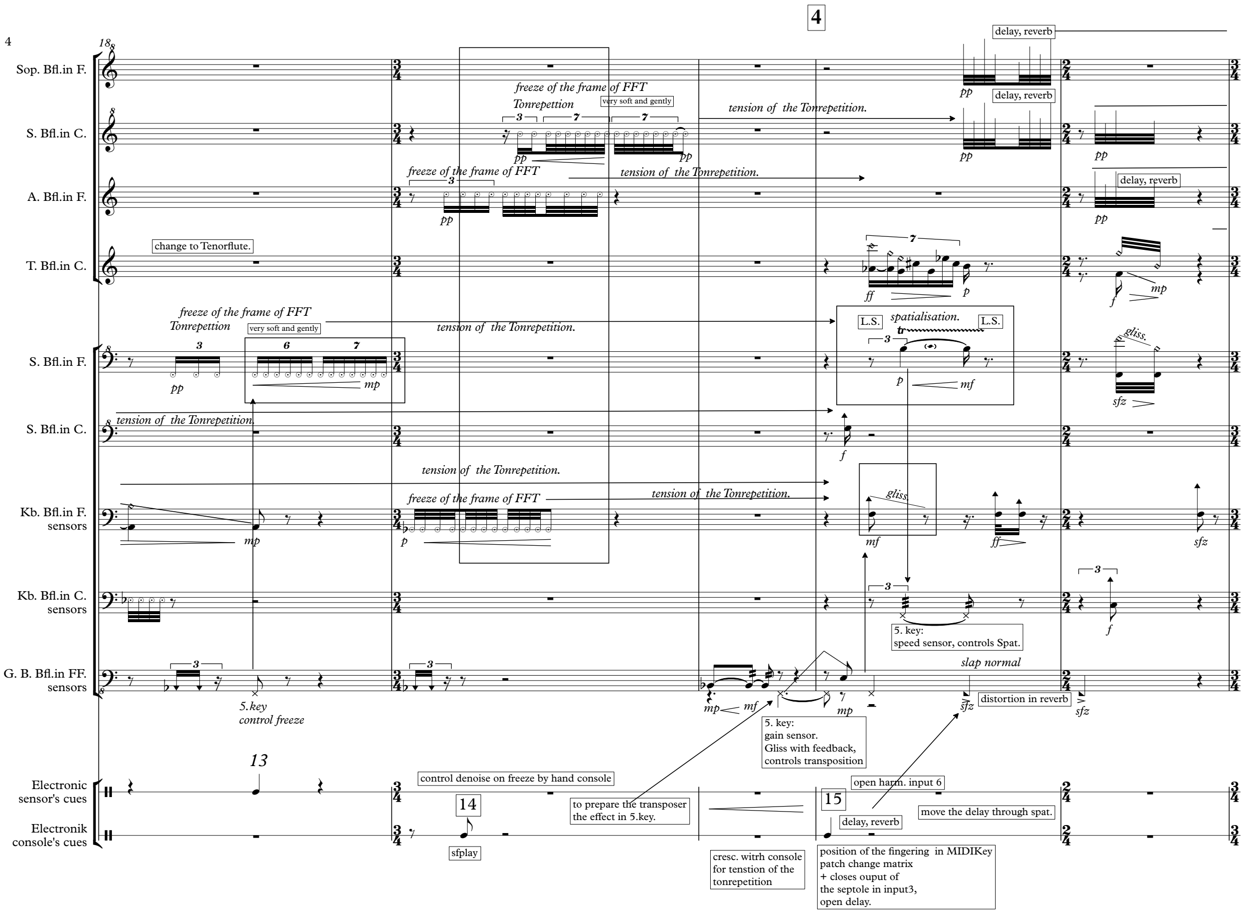

Figure 3: Excerpt from E. Garifzyanova, "Arcane II" for recorders, Paetzold recorders and live electronics (measure 21).

and the response generated by the machine are strongly connected: this happened in *Arcane II*[15], a piece in which the density of the delays applied to the sound coming from the Paetzold depended on the density of the fingering action measured within a specific time frame. This exemplifies how an acoustic musical gesture is extended via its elaboration through the electronic process.

Once again, the possibility of detecting actions directly linked to sound production makes possible an interaction in which the feedback is clear and can easily be evaluated by its originator, the recorder player. The introduction of a non-linear distortion effect is an example of this kind of interaction: the intensity of the distortion is related to the air pressure detected inside the instrument that can provoke an enrichment of the acoustic timbre in proportion to the dynamic detected. This effect simulates what traditionally happens when a player emits an *overblow*, a specific extended technique used in contemporary music where the sound not only rises in pitch but the timbre density is augmented, producing an effect similar to the above-described distortion.

Applying the same paradigm to the use of an artificial reverberator, controlled through a reaction inversely proportional to the dynamic of the instrumental sound, we were able to further enhance the dynamic dimension. *Diminuendo* directions can thus become more profound, and enlarged with respect to the spatial multidimensionality of the sound: depending on the ratio between the clean and the processed sound, the sensation of different depths of the source can be increased. This effect is best summarized by imagining a *pianissimo* level with a highly reverberating sound that is perceived as being far away from the listener, and conversely a *forte* in which the effect is completely removed, thus giving an impression of great proximity.

Dealing with the ensemble dimension played a fundamental role in determining the interaction methods selected. Indeed, the composers often used what is called *cross-transformation*, which means that the interaction with machines is derived from the interchange between the different voices. In many cases, even if there is a direct relationship between gestures and sound processes, the role played by the tracked performer not only determines the elaborations of his own sound but also the transformations of the sound of other elements in the ensemble. This introduces a multi-layered typology of interplay into the writing.

FUTURE DEVELOPMENTS

Even though the project achieved its objectives (thanks to the valuable contributions of all persons involved in the research[16] and to the institutional support received[17]), a range of technical developments and new artistic projects is clearly needed to improve on and extend what has been realized thus far.

On the artistic side, if PRIME gesture research is to expand in the envisaged way, namely into musical composition, it is essential to commission new works that combine instruments and gesture-tracking and allow the musical community to reflect further on the paradigm that we have introduced.

Finally, the technology involved could be used to promote further developments in the instruments themselves, as it allows for detailed data retrieval and thus for in-depth analysis of the different components of the Paetzold recorder.

1 DO REsearch: Funding programme of the Swiss National Science Foundation (SNSF).
2 The Paetzold square recorder was invented by Joachim Paetzold and produced with his nephew Herbert from the 1970s onwards. The design of this recorder was inspired by the design of square organ pipes: this design allowed for the use of plywood to build the recorders, and this made them very affordable compared to their Baroque alternatives. The idea was thus to create larger sizes, such as great basses, contrabasses and sub-contra basses, that would be affordable for purchase by a wide public.
3 Jointly financed by the HES-SO and the HEMU.
4 Such as Frans Brüggen, Walter van Hauwe, Kees Boeke and Antonio Politano.
5 Automatically amplifies the sound via a user's definable transfer function, thus extending the "in-tune" dynamic range of the instrument from *ppp* to *mf* (instead of *ppp* to *p*).
6 E. R. Miranda, M. M. Wanderley, *New Digital Musical Instruments: Control and Interaction Beyond the Keyboard*, A-R Editions, Inc., 2006.
7 Acoustic musical instruments extended by the addition of several sensors, enabling performers to control extra sounds or musical parameters (cf. reference 1).
8 "A musical instrument designed or adapted to be used with electronic sensors whose output controls the computerized generation or transformation of the sound". (Oxford Dictionaries, www.oxforddictionaries.com)
9 The piezoresistive effect of a bended or shaped strain gauge is used to detect applied pressure, the resistance increasing as pressure deforms the material.
10 All the data is mapped between 0 and 1 and rescaled depending on the part of the electronics they have to control. This data can present a very great variety in terms of excursion: for example, the great divergence between the keys of a Paetzold requires a flexible and adaptable system (each key presents a stationary position which is completely different from the position of the other keys, which means a different distance between the body of the instrument and each of the keys). If raw data were used, its wide diversity would cause an unpredictable interaction. Therefore it is strongly recommended to calibrate the instrument before each performance.
11 All communications are based on the OSC protocol, a protocol for communication among computers, sound synthesizers and other multimedia devices that is optimized for modern networking technology.
12 A wind controller is an instrument capable of controlling one or more music synthesizers or other devices.
13 This ensemble, dedicated to the development of new music for recorders, was founded in 2008 at the HEMU within the scope of the first research project on Paetzold recorders, conducted by Antonio Politano. The ensemble was supported financially by the HEMU and the HES-SO (Haute École Spécialisée de Suisse Occidentale).
14 E. Garifzyanova, *Arcane II* for recorders, Paetzold recorders and live electronics; D. Karsadi, *Aigoo* for recorders, Paetzold recorders and live electronics; C. Wen Chen, *Verzweigender Duft* for recorders, Paetzold recorders and live electronics; R. Castagnola, *Keraynos: all'ombra del lampo* for Paetzold flute ensemble and live electronics; J. Meßtorff, *Korrosionen* for recorders, Paetzold recorders and live electronics.
15 E. Garifzyanova, *Arcane II* for recorders, Paetzold recorders and live electronics.
16 Antonio Politano, HEMU, head of the project; Angelika Güsewell, HEMU, head of the research department; Simone Conforti, HEMU, scientific collaborator; Kilian Schwoon, professor of composition, Musikhochschule Bremen; Jo Kunath, recorder builder, Germany.
17 From the HEMU, the HES-SO, and the Musikhochschule Bremen.

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