Instruments and temporal control in the context of musical communication and technology

Álvaro Mendes Barbosa
Pompeu Fabra University - Audiovisual Institute
Estació de França Paseig de Cincurvalacio, 8 Desp. 391
08003 Barcelona, España – http://www.iua.upf.es
tel.: +34 93 542 2588, email: alvaro.barbosa@tecn.upf.es

In principle talking about musical performance (or temporal control) implies an instrument and a performer.

The performer and the instrument form a complex sensorial Feed Back system in which the performer actuates on the instrument and the changes that occur in the generated sound will influence the performer's actuation in the following moment.

However the characteristics of the sensorial feed back system between the performer and the instrument go beyond the auditory events since the physical and visual interaction also plays important roles.

It is also important to notice that this system evolves to different stages, along with the training that is required for a performer to control the instrument on a consequent way.

1. Traditional Music Instruments VS Virtual Music Instruments

The aim of an instrument is that somehow a performer can control it with body gestures and produce music with it.

Traditional Musical Instruments – Focus on pitch and dynamics changes. The performer can actuate on the instrument only by changing its notes and their amplitude. The general timbre of the instrument is modeled by the physical characteristics of the instrument and if it can be changed usually it is not in an interactive way during the performance.

Virtual Music Instruments – With electronic/digital media developments, specially in computer science the possibility to control every parameter that modifies sound became possible, however even today there is a tendency to recreate the traditional music instruments interaction model that focus on pitch and dynamics.

Transformation of timbre using computers through spectral modeling of sound is probably the greatest potential of what we can call a Virtual Music Instrument.

The three most common approaches for the implementation of Virtual Music Instruments are:

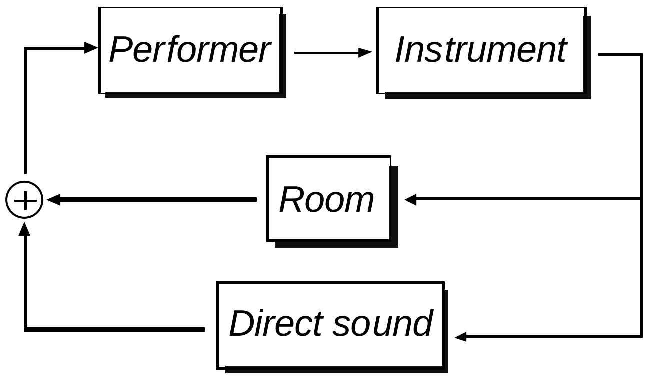
- Considering that any interactive system that produces music, which can be manipulated in real time, is in fact an instrument. Different levels of interaction can be required for different instruments.
  Examples: the Theremin, the Meta-Instrument, etc.

- Considering only pure synthesis, not taking in account a physical interface with the performer.
  Different types of synthesis can be used: Additive, subtractive Non-Linear and the performer could also be the computer or any sound reproduction media.
  Examples: algorithmic composition, tape composition, etc.

- Synthesis of Traditional instruments: recreation of natural sound modeling the physical structure of traditional instruments in terms of its acoustic properties and its user interface in a away that resembles the original instrument.
  Examples: midi pianos, electronic violins, etc.

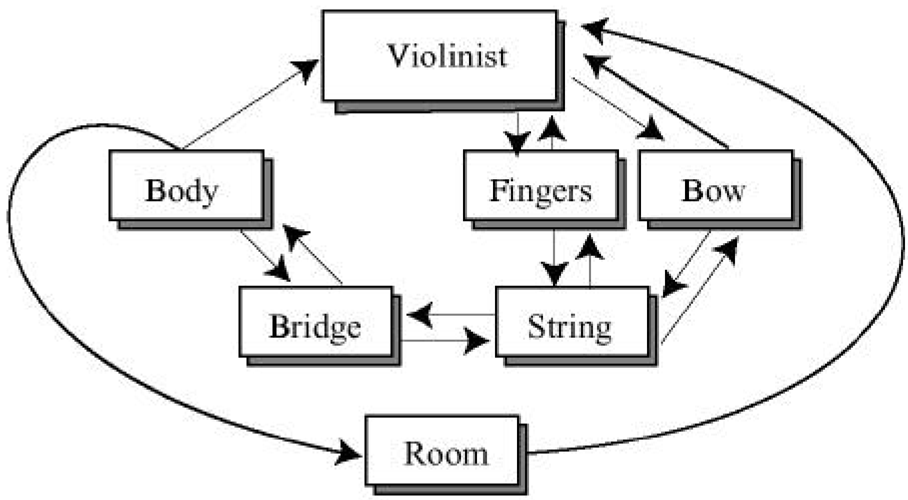
2. Models of interaction

The diagram representation of a performer actuating over a traditional instrument is a quite simple feed back Loop.
The real time auditory feed back can either be the result of the acoustic transformation that the room applies to the instrument sound, mixed with the direct propagation of the sound from the instrument straight to the performers ears, or in the case of an anacoic chamber or a setup with amplification and headphones only the direct sound that outputs from the instrument.



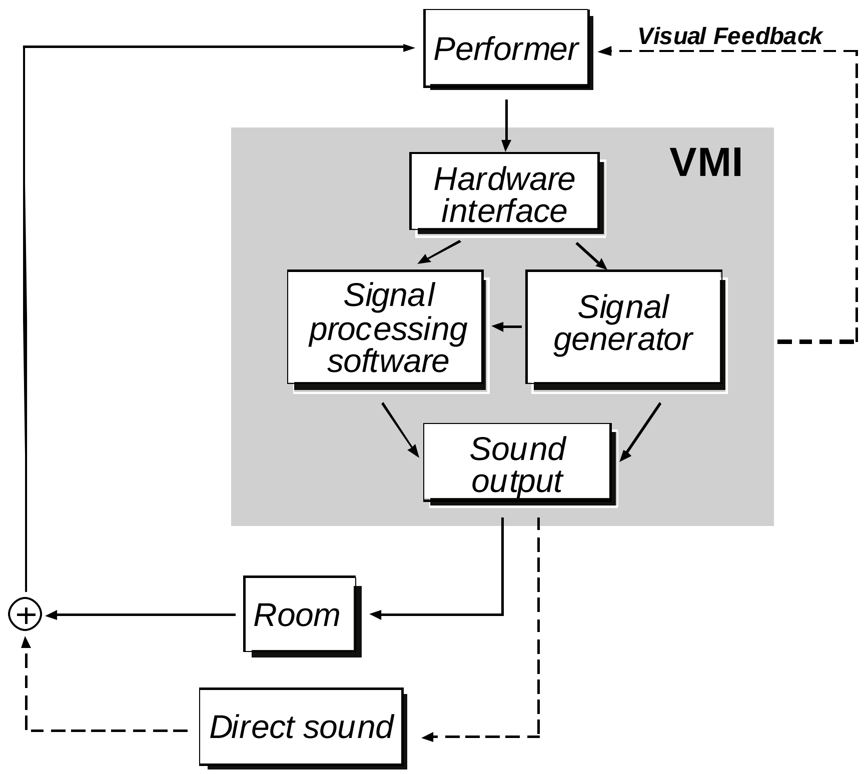
Although its not represented in the diagram, the sensorial Feed Back that the performer receives from the instrument while playing it is not only auditory. The physical structure of the instrument has also great influence on the physical gestures of the performer.

The following Diagram represents a more detailed representation of the sensorial feedback system that concerns the physical structure of an instrument using the example of a Violin.



In the following diagram is represents a general system of a performer actuating over a Virtual Music Instrument.

The feed back between the output of the virtual device and the user must be in real time so that the system can be classified as an instrument.



The Hardware Interface can actuate on the Signal Generator typically to vary the Pitch and Dynamics like in a traditional instrument, but it can also actuate on the Signal processing software and therefore transform all kinds of parameters.

The signal processing software emphasis is usually on the spectral modeling of the signal allowing the user to change the timbre of the generated sound and also its pitch and dynamics. It is also possible to actuate in other parameters of sound like Specialization and duration at the processing stage.

Many systems work only with one instance of the hardware interface actuating either in the signal generator (in many cases impersonating traditional instruments) or in the signal processing stage in which case the signal generator is replaced by a sound file or an input line from microphone capturing an acoustic sound.

In this diagram the sensorial feedback system related with the physical structure of the interface is also not represented in detail, but it is of great importance and most of the times will determine the success of the instrument, however due to the experimental nature of this kind of devices the hardware interface is totally different from case to case.

In a VMI the direct sound could be considered the output of the signal generator, which many times is not outputted from the system.

It is also important in many situations that the visual feedback from the system software usually presented on the computer screen is accessible to the performer.

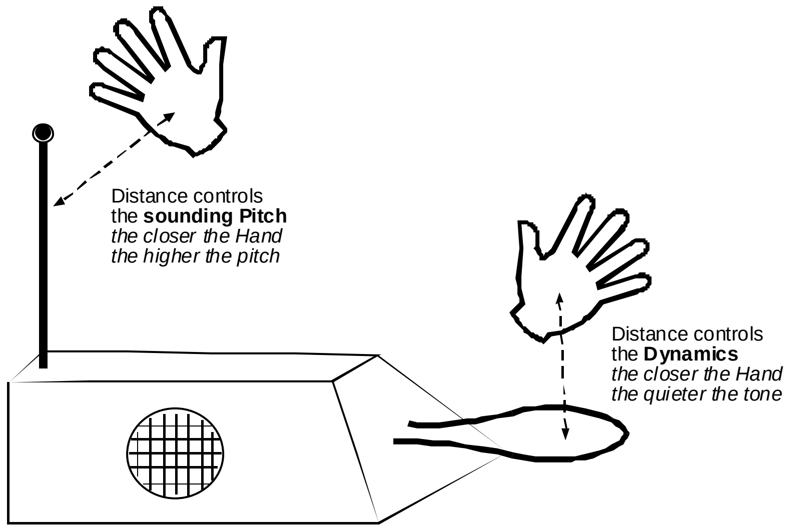
3. Historical landmarks and references of virtual music instruments

The Theremin – Leon Theremin, 1920

The idea of performing on a musical instrument without touching it, merely by waving one's hands in front of it, was sheer magic! Even today the playing technique retains a strange, supernatural quality and a certain poetic aspect.

The Theremin was invented by the Russian Physicist Leon Theremin in 1920, and is an early example of a truly electronic instrument.

The Theremin allows the user to change the frequency of an oscillator, and there by changing the pitch of the sound, by moving his hands closer to or further from the upright antenna. The user can also control the volume of the sound by moving his hands closer to or further from the horizontal antenna.



In 1928 Leon Theremin met the extraordinary Russian musician **Clara Rockmore** that became the greatest Theremin virtuoso ever.

Example: 1977 recording supervised by Robert Moog of Clara Rockmore (Theremin) and her sister Nadia Rosenberg (Piano) performing "*Carnival of the Animals, The Swan*" by *Saint Saëns*.

Trautonium - Freidrich Trautwein, 1930

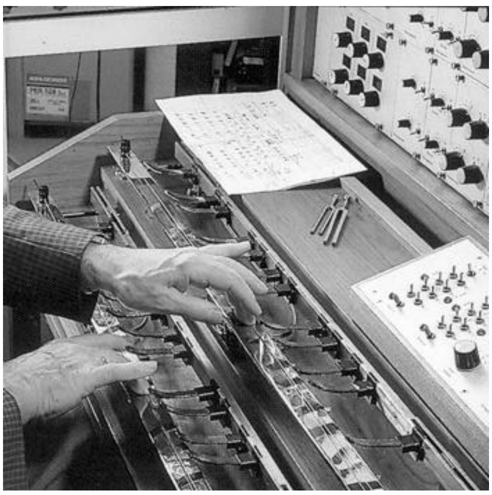
The Trautonium was developed by the electrical engineer Freidrich Adolf Trautwein at the Berlin Academy of Music and it was manufactured and marketed by Telefunken between 1932 and 1935.

The Trautonium had a fingerboard consisting of a resistance wire stretched over a metal rail marked with a chromatic scale and coupled to a neon tube oscillator. The performer pressing the wire touches the rail completing the circuit and the oscillator is amplified via a loudspeaker. The position of the finger on the wire determines the resistance controlling the frequency and therefore controlling the pitch of the oscillator. An additional series of circuits can be added to control the timbre of the note by amplifying the harmonics of the fundamental note, non harmonic partials can also be added by selective filtering. This unique form of synthesis produced a tone that was distinctive and unusual when compared to the usual valve instruments of the 1920-30's. The foot pedal of the machine controlled the overall volume.

As opposed to the synthesizers, which are played with organ like keys, the Trautonim offers the intonation of fretless string instruments as well as major virtuoso demands.

The German composer **Oskar Sala** took over the development of the Trautonium and in 1952 he built the **Mixtur-Trautonium** based on the original Trautonium but using semiconductors, and adding wire-covered catgut strings, which acted as variable resistors. According to the position at which they were pressed against the contact rail beneath them, they would control the frequencies of the electronic sound generators.

The most famous example of Sala's music and sound effects work is in Alfred Hitchcock's thriller "The birds".



Example: Oskar Sala performing "Fantasy in three parts for Mix-Trautonim Solo (1988/89), 1st part- Demonstration.

Imaginary Landscapes N·4 - John Cage, 1954

John Cage's piece, “Imaginary Landscape No. 4” (for 12 Radios), is an early example of a musical performance which combines human and a non-traditional electronic '*instrument*'. The piece was scored for 12 radios and 24 people. For each radio, one person would control the volume and another would control the frequency. The result was a musical piece in which one, several, or all radios would be playing different stations at different volumes simultaneously.

Groove - Max Mathews, 1970

GROOVE is an early example of interactive music with computers designed by Max Mathews and F. Moore at ATT Bell Laboratories in the late 1960's. GROOVE is a Computer software (runs over the Honeywell DDP-224) that allows a user to control 14 ‘functions of time' simultaneously in real time on a sound synthesizer. These ‘functions of time' are used to control various parameters of a song such as speed, volume, and waveform.

The music one hears is the sensory feedback, which closes the loop and allows the user to make further adjustments in real-time.

In principle, GROOVE was a hybrid modular synthesizer. It allowed the arbitrary interconnection, via user-programmed logic, of analog and digital input, output, hardware, and software modules, including library-resident code modules written by users over the year, and increasing numbers of gizmos built mostly by Max Mathews.

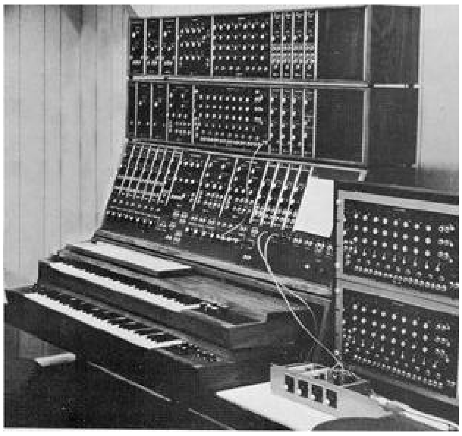
Synthesizers

Moog – Robert Moog, 1964

Robert Moog starting out in 1961 building and selling Theremin kits and gaining knowledge about transistorized modular synthesizers, that resulted on the design and implementation of the first widely popular analog electronic synthesizer in 1964.

A 1968 recording of the music of Johann Sebastian Bach performed on a Moog synthesizer by Walter Carlos, entitled “Switch on Bach” became one of the best selling classical music albums of all times. the unique sound of the Moog synthesizer enchanted millions of people.

Example: Walter (Wendy) Carlos performing “Switch on Bach” in the Moog Synthesizer.



Modular Moog Synthesizer c1967 **Yamaha DX7 Synthesizer**

Yamaha DX7 – Yamaha corporation, 1983

The developments that lead to the final implementation of DX7 Synthesizer, first started with the research that the electronic music composition teacher **John Chowning** was conducting at Stanford University with high-speed vibratos in the late 60's that resulted in the beginning of modern Frequency Modulation (FM) synthesis implementation for musical purposes in 1967.

In the 70's Yamaha starts to develop in Japan an instrument prototype based on John Chowning FM Synthesis techniques using digital technology, resulting in a monomorphic synthesizer entitled MAD in 1973.

After a very confusing situation regarding the involvement of John Showning and Stanford University in the project that Yamaha was carrying out finally the DX7 was launch in 1983. The final product was a 16-voice polymorphic digital synthesizer offering 32 internal memories plus a ROM/RAM cartridge slot.

The sounds generated by the DX7 where based on a series of sine wave oscillators (called operators) that according to different algorithms (configurations) would be combined as carrier or modulator waves resulting on the final sound. The DX7 can use six operators per voice.

The DX7 not only redefined what a synthesizer sounds like, but above all it redefined the synthesizers market, being considered as the greatest selling synthesizer in History (180.000 units).

The Midi Protocol – first published in 1982

MIDI (Musical Instrument Digital Interface) resulted from a consortium formed by three synthesizers Manufacturers (Sequential Circuits, Roland Corporation and Oberheim Electronics) in an effort to standardize a control a communication protocol that would permit several digital synthesizers to play simultaneously in a synchronized way. The final specifications of Midi 1.0 were published in August of 1983, and up until today it has never been upgraded.

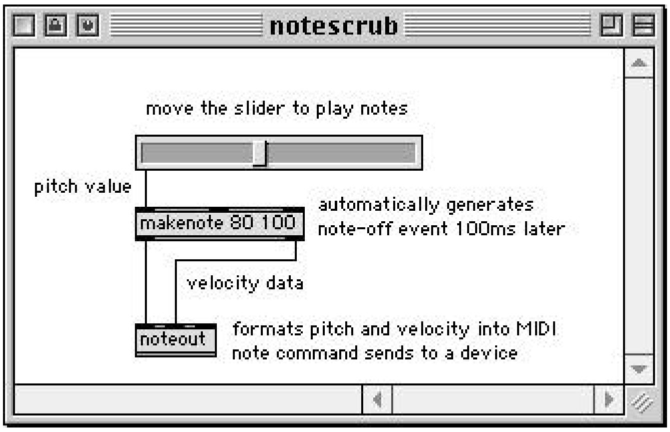
Although MIDI has several technical and artistic limitations the fact that it remained unchanged allowed the development of a very significant community of users.

Also due to the fact that midi does not actually describe what the devices must do, only how to communicate between different devices, we can find that most of the research being developed these days involving virtual interfaces and interactive music use MIDI as a control protocol.

Max - Miller Puckette, 1985

In 1985 at IRCAM (Institut de Recherche et de Coordination Acoustique/Musique, founded by composer and conductor Pierre Boulez), Miller Puckette, wrote a program for Macintosh computers, using concepts he had learned from Max Mathews, ending up calling the program MAX.

Max is an object oriented graphical programming environment for music and multimedia that became a widely used platform in computer music research and interactive production, due to its easy to use modular interactive interface that includes the possibility of advanced programming. As shown in the picture one can create MAX programs only by wiring together objects.



The software was first distributed commercially by Opcode Systems in 1990 and is now available from Cycling74.com.

The IRCAM real-time development team has since reimplemented and extended this software under the name JMAX, which is distributed free with source code.

Hyperinstruments Group - Tod Machover, MIT Media Lab, 1986

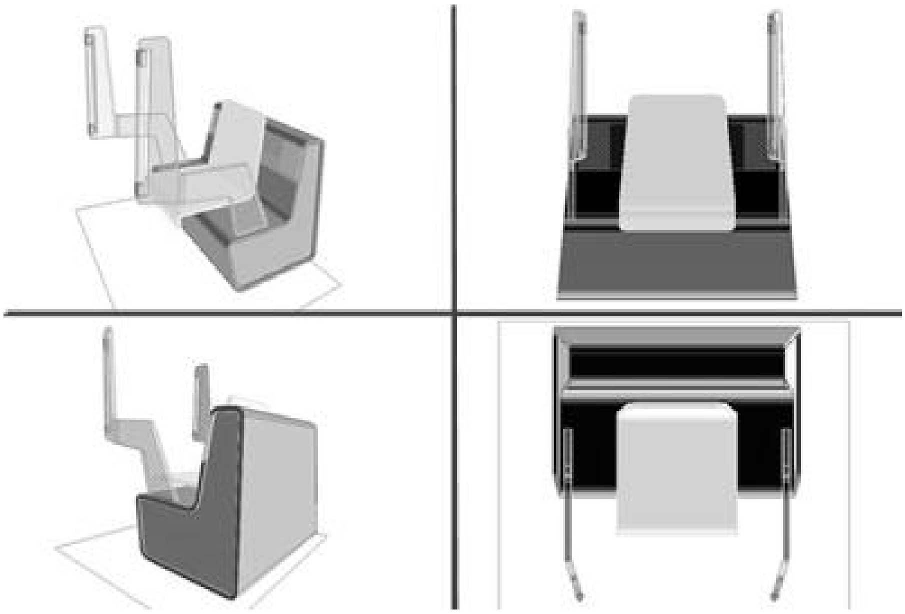
The hyperinstrument project started in 1986 with the goal of designing expanded musical instruments, using technology to give extra power and detail to virtuosic performers. Such hyperinstruments were designed to augment guitars and keyboards, percussion and strings, and even conducting.

Examples of Hyperinstruments projects at Media Lab are the **Brain Opera** or the **Musical Jacket**.

Brain Opera - *http://brainop.media.mit.edu/*

The Brain Opera project connects a series of hyperinstruments designed for the general public with a performance and a series of real-time music activities on the Internet. Audiences explore the hands-on instruments as preparation for the performance, creating personal music that makes each performance unique.

The final version of the Brain Opera will be permanently installed at the House of Music in Vienna, Austria.



One example of a Hyperinstrument in the Brain Opera is The **Sensor Chair**. The instrument consists of a chair where the visitors can seat and by waving their hands in front of two Theremin-like antennas they create music that contributes to the final piece.

Musical Jacket - *http://www.media.mit.edu/hyperins/levis/index.html*

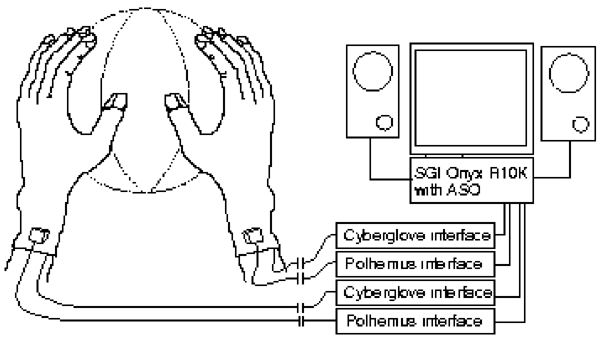
The Musical Jacket is a wearable hardware device. A Levi's jacket that has been transformed into a complete musical instrument, with keyboard, synthesizer, and speakers.

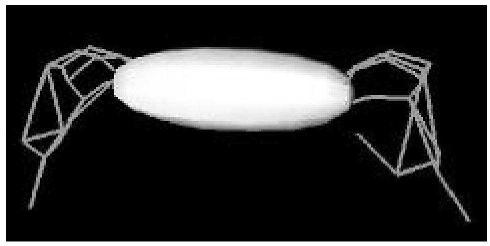
Example: Mpeg videos of Musical Jacket Music System Explanation by the developers of the project.

Sound Sculpting – Axel Molder, 1998

Sound Sculpting is a real-time design environment for Virtual Musical Instruments developed by Axel Molder at the School of Computing Science of Simon Fraser University in Canada.

The environment allows the user to create, edit or perform sounds by changing parameters like position, orientation and shape of graphically displayed objects that can be programmed to behave in any manner desirable, like for instance, being mapped into sound parameters. Manipulation occurs with either one or both hands wearing datagloves.





Example: QuickTime video of a performance with Sound Sculpting.

Digital dance system - Wayne Siegel and Jens Jacobsen, 1997 Danish Institute of Electroacoustic Music(DIEM).

This project approaches the reverse process of “Dancing to Music” on an aesthetic perspective. In this system the performer “Dances The Music”.
The goal of the project is to address questions like:

- What is the role of the composer?
- How can a dancer’s movements on stage be translated into music?
- Is it possible for a dancer to control compositional processes in a musically meaningful way while dancing?
- How are the roles of the choreographer and dancer affected when the dancer is placed in control of a musical performance?

Several motion tracking sensor technologies where tested in this project including the STEIM BigEye video Tracking system, the Midi Dancer wireless body suit, and power glove systems.

The Working team ended up constructing a set of wireless sensors produced by hand that could measure the bending of joints on the dancer’s elbows, wrists, hips and knees. These values where mapped into MIDI and processed in a Macintosh workstation running a software synthesizer programmed under MAX.


Before a final composition of a piece with three musical sections was successfully concluded, an exhaustive movement study was performed with this system.

The QwertyCaster - Sergi Jordá, 1997 Audiovisual Institute -UPF

The QwertyCaster developed by Sergi Jordá is excellent example of the use of cheap traditional technology to create a Virtual musical Instrument. Using a metaphor of a Stratocaster Guitar Sergi used a computer Keyboard, a track ball mouse and a joystick as the sensors to actuate on parameters of a sound synthesis software he developed.

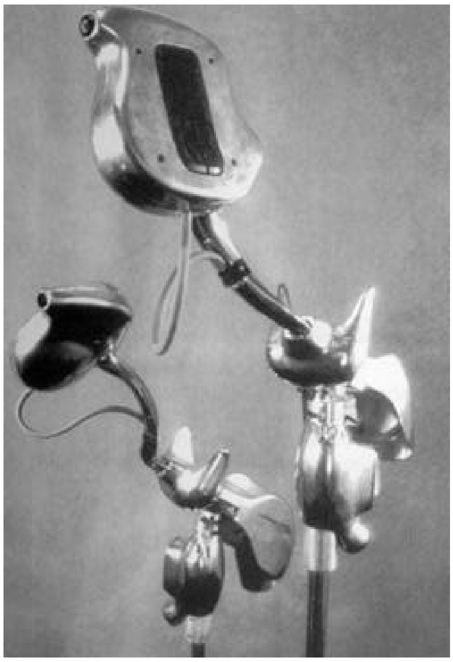

The QwertyCaster is often used in the FMOL-Trio Performances based on the FMOL (F@ust Music On-Line) software.

Meta-Instrument - Serge Laubier, 1998 Espace Musical

The Meta-Instrument is a musician machine interface and gesture transducer intended for electroacoustic music, multimedia work, and, more generally for controlling algorithms in real time.

The main Specifications of the instrument are:

- It is able to simultaneously and independently control 32 independent 7-bit variables.
- Its mechanical structure complements the way the body works, so has to allow analogies between gesture and sound movement.
- It is easily portable, and it's digital data is transmitted using MIDI
- It is fun and pleasant to play like a musical instrument and not like a machine



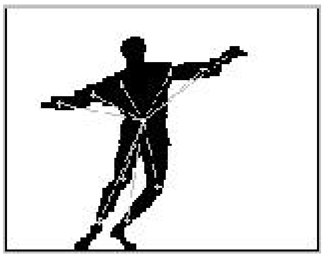
The sensor system is based in two symmetrical mechanical articulated arms with several buttons and two-foot pedals. The resulting gesture and movement data streams are transmitted over MIDI to a Macintosh computer running a program developed under MAX that processes the data and actuates over a sound synthesizer that finally outputs the sound.

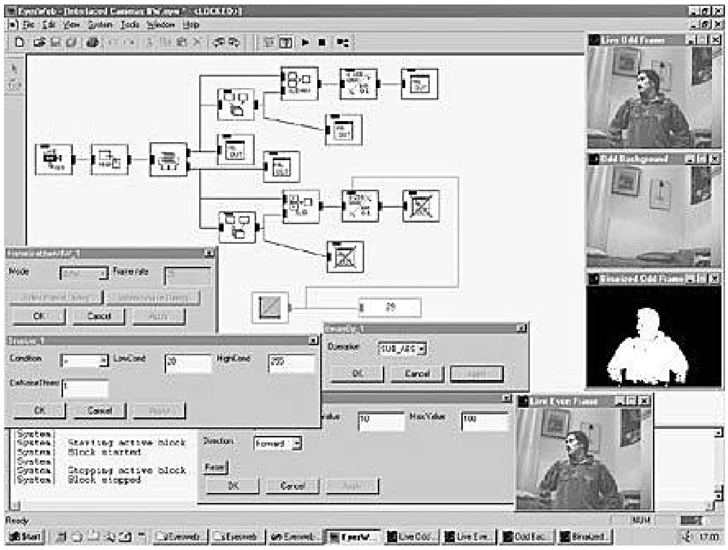
The computer's screen is placed in front of the performer so that he can have visual feedback of the software behavior.

The team that developed the instrument is working with 5 composers in 11 different styles of music for 35 different configurations (mostly software) of the instrument.

Eyes web - Antonio Camurri, 2000 Laboratorio di Informatica Musical of Genova University.

Eyes Web is a system for the real-time analysis of full-body movement and gesture of one or more humans, with a special focus on expressiveness in movement. Such information is used to control and generate sound, music, visual media, and to control actuators (e.g. robots).





Yamaha Disklavier – Yamaha Coorporation

The Yamaha Disklavier piano series are regular acoustic pianos on which the keyboard is connected to a set of sensors that can control and be controlled by MIDI. The Original concept was to allow a pianist to record his performance to midi and to add training possibilities, having the piano performing from a midi score for students to practice.

However, the fact that one can actually control an acoustic piano with MIDI created an excellent opportunity to develop interactive music projects that include an acoustic piano live performance.

An example of the use of the Disklavier piano on this context is the real time nuance based audio-visual performance “Haitch”, commissioned by the ZKM Museum (Zentrum für Kunst und Medientechnologie) in Germany to the Polish composer Jaroslaw Kapuscinski.

In his performance kapuscinsky had a midi keyboard in the backstage that would simultaneously control a Yamaha Disklavier Piano performing “alone” for the audience, and at the same time would control a software program developed under MAX using the NATO library to manipulate a set of short videos from a dancer performing according to the development of the music score. The projection of the final video was also controlled in real time and it was projected on a hanging screen over the piano.

4. How to do it

Gesture Acquisition

Research on gesture has been carried out in many different fields and there are many categories in this subject such as Instrumental gestures, dance/music interfaces, conductor's gestures, natural gestures, sign language, etc.

If we focus on the case of **instrumental gestures**, one can divide gesture capture techniques according to the following capture strategies:

Direct gesture acquisition - one is capturing the actual physical gesture or movement through the sensors. These sensors may or may not need physical contact to transform the gestures into electrical signals.

If physical contact is involved, they can be called **Haptic,** otherwise, **Non-Haptic.** The sensors can, in turn, be classified as to whether the sensor outputs are *continuous* or *discrete* values of the variable sensed.

Indirect gesture acquisition – one looks for the gesture in the sound produced by an instrument. It is well known that the sound produced by an acoustic instrument is a direct result of the physical properties of the instrument, the acoustics of the room where the instrument is being played, and the gestures applied to generate the sound by the performer.

If we can isolate the influence of the room and also know the physical behavior of the instrument, it is then possible to deduce information about the gestures used to produce the sound from its analysis.

This technique is usually harder to perform than direct acquisition due to expensive processing power, complicated algorithms necessary to identify different gestures, etc.

Indirect acquisition has the potential to give a better result than direct acquisition, since the sound contains the whole gesture information that caused it.

Mapping

There are many ways to relate the output of the sensors that is capturing the performers gesture and movement with the input parameters from your software synthesizer and sound generator.

The most common way to do it is to assign ONE controller output to ONE parameter, like for instance:

- breath pressure maps in to duration
- hand distance maps in to volume
- fingering maps in to pitch

This is commonly known as **One-to-One mapping**.

In many systems a one-to-one mapping may not be sufficient, since it can only reproduce some points of the entire gesture from, in which case one could consider having more than one controller parameter mapped a single musical parameter.

One may also wish to map controller parameters to synthesis parameters in different ways, such as using metaphors in order to manipulate sound characteristics, reducing the complexity of the system and of the interaction.

5. Commercially available technology

Implementing a basic virtual music instrument using commercial or public domain available technology has become fairly easy.

The most common setup is based on a set of sensors that connects to an analog to midi interface. The midi data is transmitted to the computer, which is running the software, and finally an output is generated based on the mapping of the midi signals on the sound parameters that we decide to manipulate.

The synthesis software can be developed with plain programming languages or with software packages designed to manipulate audio signals and to control other devices

Software development platforms

- **Cycling'74 *Max*** graphical programming environment for the Macintosh platform *(http://www.cycling74.com/)*

- **Cycling'74 *MSP*** set of audio and signal processing objects for MAX *(http://www.cycling74.com/)*

- **Eusocial *NATO.0+55*** set of modular video processing and QuickTime control objects for MAX *(http://www.eusocial.com/)*

- **Ircam *Jmax*** freeware graphical programming environment for Linux platform *(http://www.ircam.fr/jmax/)*

- **Miller Puckette *Pure Data*** freeware graphical programming environment for Linux and Windows platform *(http://www-crca.ucsd.edu/~msp/software.html)*

The conversion of the gesture and movement to midi data can be achieved with several commercially available sensors and analog to midi interfaces.

Haptic Sensors

- The Haptics Community *(http://haptic.mech.northwestern.edu/)*
- Infusion Systems sensors *(http://www.infusionsystems.com/)*

Non Haptic Sensors

- **Steim** ***BigEye*** computer software designed to take real-time video information (video tracking) and convert it into Midi messages in the Macintosh platform. *(http://www.steim.nl/bigeye.html)*

A comparison of analog to MIDI interfaces

The Discussion Group on Gesture Research in Music at IRCAM did an extensive comparison of different available analog to MIDI interfaces.

http://www.ircam.fr/equipes/analyse-synthese/wanderle/Gestes/Externe/

The comparison refers to the interfaces:

ADB I/O (BeeHive Technologies Inc.), **AtoMIC-Pro** (Ircam), **CVM** (DIEM), **Digitizer I-Cube** (Infusion Systems), **MIDIbox** (NOTAM), **MIDIBrain** (PAiA), **Midicreator** (York Electronics Centre), **Sami** (B.Donzel- Gargand & A. Lefèvre), **Sensorlab** (STEIM)

6. Additional considerations

Live musical performances are traditionally related to the effort and skills of the performer.
In this sense to preserve the magic of an interactive music performance especially over computer base virtual music instruments one should consider that:

- The role of the performer and the computer should be very clear
- The actions of the performer should have very clear consequences, and the interaction should be perceived by the audience
- Although the consequences of the performer's actions should be very clear they should not be predictable and in this sense the interaction process should not be totally understood by the audience
- If the interaction process is to obvious and the audience is not surprised by its results, the performance becomes a technology demonstration.

One final important consideration to take in account when designing a VMI is that even the most advanced instrument in the world still has to have a repertoire, which must be played for the instrument to survive. The violin would not have the same success today if it did not have a sufficient number of compositions dedicated to it. In this sense the creator of the instrument should provide that his instrument could be accessible to musicians and composers as much as possible.

References:

[1] The hyper instruments group at MIT's MediaLab - *http://www.media.mit.edu/hyperins/*

[2] Laboratorio di Informatica Musical of Genova University - *http://musart.dist.unige.it/*

[3] Danish Institute of Electroacoustic Music (DIEM) - http://www.diem.dk

[4] Articles form the Computer Music Journal - MIT Press - Spring, Fall and winter of 1998, Spring 2000

[5] Gravikords Whireless & Pyrophones - Experimental Musical Instruments, Bart Hopkin, 1996 Ellipsis Arts

[6] IRCAM Institut de Recherche et de Coordination Acoustique/Musique - *http://www.ircam.fr*

[7] Reinventing the Violin by Daniel Trueman, 1999

[8] Discussion Group on Gesture Research in Music at IRCAM - *http://www.ircam.fr/equipes/analyse-synthese/wanderle/Gestes/Externe/*

[9] Introducción a los sistemas musicales interactivos by Sergi Jordá, 2000

[10] Trends in Gestural control of Music edited by Marcelo M. Wanderley, Ircam – 2000

[11] Virtual Musical Instruments: Accessing the sound synthesis universe as a performer by Axel Mulder, 1994

[12] Human movement tracking technology by Axel Mulder, 1994

[13] Computer generated music composition by John Chong Yu, MIT 1996

[14] Working Group on Interactive Systems and Instrument Design in Music - *http://www.notam.uio.no/icma/interactivesystems/wg.html*

[15] Audiovisual Institute of Pompeu Fabra University - *http://www.iua.upf.es/*