Dancing the Robots: in per- and retrospective.

Although not so obvious for musicians these days, it appears to be clear that there is no great -if any- future for musicianship in the traditional sense. The reasons are manifold: first of all, why would the collection of instruments thought at our conservatories be suitable for expressing musical needs of our time? These instruments all have been developed in the 18th and 19th century and therefore are perfectly suited for playing the music of that past. There is no ground for a claim that they would be suitable for music of our time. Moreover, learning to play these instruments well, is a tedious job and the overall quality of players is going down at a steady pace. After all, who nowadays wants still to spend eight hours a day of her or his youth, practicing the violin? It is not at all amazing that the finest players of these antique western instruments now invariably have an Asiatic or Russian (for the time being...) background. What we see in our culture is that in all fields of craftsmanship, automation made its appearance: we drive cars, use welding robots to make them. Computers are omnipresent and can be found in even the simplest household appliances. Lathe work is replaced by CNC machining, the entire printing and publishing business is automated, aircraft can fly without pilots and even with them still present, heavily rely on automation. So how come music production is not yet fully automated? In reality though it is already to a large extend: in commercial music, most shows are merely playback... 'Serious' music has long thought to have escaped from this. After all, only a very partial truth, as most 'classical' music is consumed via media as Cd's, broadcasts and Internet and these recordings are the result of a high degree of automation anyway.

In 'serious' contemporary music however, experimentalists have since the beginning of the 20th century shown great enthusiasm for the possibilities offered by technology. Thus electronic music, electronic instruments and computer software to generate, manipulate and treat sound, were developed and found many adepts. The endeavors of those experimentalists even found an outlet in commercial musics of kinds.

However, as it came out, electronic instruments have proven not to be the exclusive alternative for the traditional instruments of the past. One of the fundamental problems with electronic sound-generating instruments of any kind is that their final sound production relies exclusively on the use of loudspeakers. These devices virtualize the sound as they obscure the real origin of the acoustic vibrations we call sound. As a consequence, the performer using electronic instruments finds himself on stage deprived from the fundamental tools essential for musical performing rhetorics. The actions required to produce sounds being arbitrary, irrelevant and in any case dissociated from the resulting sonic reality. This dissociation undermines the convincing power of live electronics to a great extend. To put it extreme: there is no noticeable difference between playback and real-time music production. The human body becomes obsolete.

For this amongst other reasons, we noticed a lively interest amongst experimentalists to turn 'back' to real acoustic sound sources.

In our own career, we have gone through all stages: starting using and designing analog electronic equipment since the late sixties and in the early seventies, delving into digital technology since the very early eighties until we started applying our competence in electronics to real acoustic sound production. This is where the robot orchestra we have been working on since the late eighties comes from. The crucial idea behind it was, and still is, that we wanted to automate the control of the sound source to the largest possible extend, yet always preserving the acoustical sound production. Thus amplification became our taboo as it would introduce the loudspeaker.

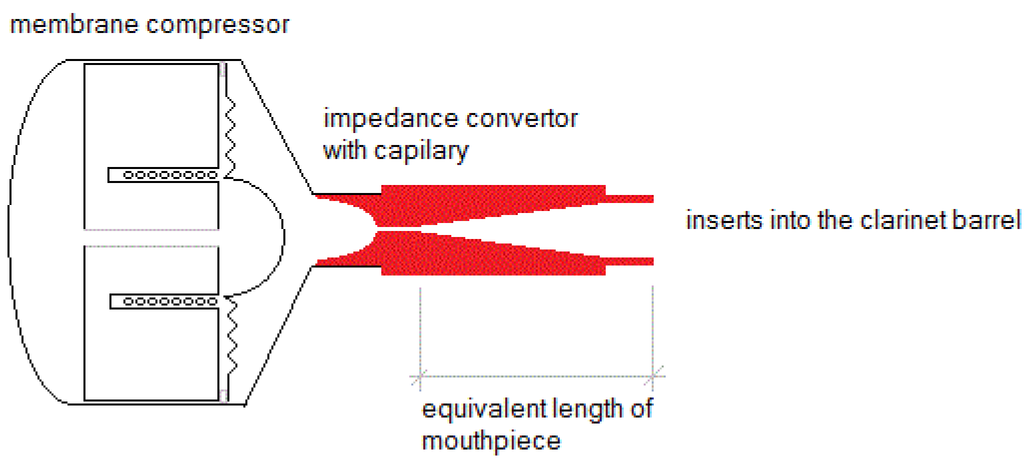
The robot orchestra basically consists of two categories of automated musical instruments: at the one hand we have novel sound sources and noise makers and at the other, existing musical instruments that we attempted to automate as fully as possible including many extended possibilities hitherto unimaginable to achieve from the same instruments when played by humans. For a complete description of the orchestra, at the time of this writing consisting of 60 robots, we refer to the catalog available on the Logos Foundation's website [4]. Here we will limit ourselves to two single cases, one for an automated existing instrument in casu that of the robotic clarinet as we realized it in 2012, and one for a newly invented instrument, in casu <Whisper>, built in 2013.

<Klar>

A somewhat rare instrument became the starting point of this robot: an alto clarinet built by Higham in Manchester in the first half of the 20th century. It's an Eb instrument, a fifth lower than the regular Bb clarinet. and thus reaching down to G (midi 43) in absolute pitch. So in a way it comes pretty close to the basset horn, normally in F but reaching down to F (midi 41). In any case it's an instrument that never found its way into the regular symphony orchestra, nor is there any classical repertoire -at least to our knowledge- for this instrument. It has a curved metal bell and is made -presumably- of coconut wood. The mouthpiece is connected to the instrument through a bent neck also made of metal. The tuning conforms to A=440Hz. Here is a picture with the neckpiece removed:

For the design we benefited from the experiences gained with previous monophonic brass instruments such as <Korn>, <So>, <Heli>, <Bono>, our <Autosax> -a single reed instrument-, as well as the double reed instruments <Ob> and <Fa>. Our prime concern - next to sound production itself- was to make the mechanical parts as quiet as possible. <Ob> and <Fa> in that respect were the most succesful so far, but in a clarinet the forces needed to open and close the valves are quite a bit higher than on the oboe. On the other hand the solution that has made <Fa>, the bassoon, a success cannot be applied here: in <Fa> we removed all existing valves and replaced them with solenoid driven pallet valves directly mounted on the bassoon. The clarinet body however just does not offer enough space to make that a viable solution. Thus we had to find something in between what we realized for <Ob> and <Fa>. Some original valves were removed and replaced by solenoid driven valves mounted on a separate chassis. For other valves we left the original valves and springs in place, but operated them with felt or rubber padded solenoids replacing the human fingers.

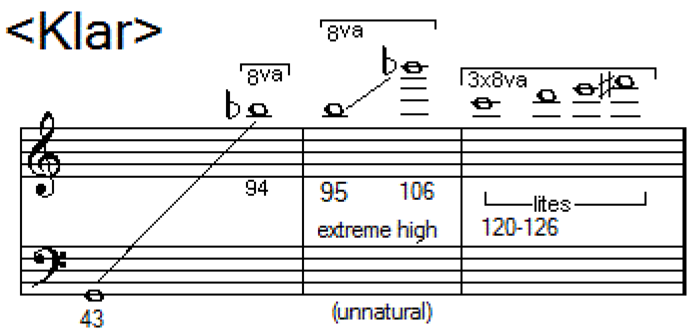
The sound driver follows a recipe that has proven its validity over many previous wind instrument robots: the membrane compression driver followed by a capillary impedance convertor. Obviously the impedance convertor we finally inserted (after having made many models on the lathe) has quite different proportions than the ones used for the brass and double reed instruments. One of the problems was to work out empirically the equivalent acoustical length of the clarinet mouthpiece. There are -so far as we could find out- no mathematical models available. It is known in acoustics that a single reed can be considered to be a flat bar clamped at one end, but if we look at the spectrum produced once the reed is mounted on the mouthpiece and coupled to the resonator (the clarinet proper), almost nothing of this theory seems to hold true. What we do know is that the pitches that can be produced on the clarinet, must be below the natural frequency of the reed. Thus the reed is the limiting factor for the ambitus of the instrument. As we do not have this limit in our design, we can extend the ambitus of the clarinet way beyond what is possible on a normal instrument with a reed. Because of the lack of an abstract mathematical model, our approach in the design of the impedance convertor was simply musician's insight (I happen to be a former though none too great clarinettist myself...) combined with trial and error by successive approximation.



It is not by accident that the clarinet came to join the robot orchestra much later than all the previously realised robotic wind instruments. In many respects, the clarinet poses many more implementation problems than brass or double reed instruments, for its expressive possibilities are the widest of all wind instruments. First of all, there is the extreme dynamic range: a clarinet can really play ppp as well as being capable of producing a hefty fff. That's close to 110dB, well above what is reachable with 16 bit dsPIC or other similar processors. Furthermore, through reed control, the timbre of the sound is modulated continuously. This called for a pretty complex compression driver with many parameters, leading to a wealth of controllers for the user. Then of course, there are the 'special' playing techniques such as vibrato, flatterzunge (fluttertongue, a form of chopped amplitude modulation), multiphonics of different kinds as well as quartertones and microtonal inflections. Because of these complexities, we called in the services of a true 32-bit ARM processor. The firmware models the drive of an acoustic clarinet, including the spectral duodecime component and its slight detuning (or shifting phase), a formant filter with resonance, as well as the typical reed noise.

As in some previous robotic wind instruments, here again we implemented some form of movement: the clarinet together with the valve chassis are suspended in a cradle and can perform pendulum-like movement. The mechanism is controlled by two dented wheels (gear ratio 1:6) and a heavy duty stepping motor. The position of the instrument is read by a tilt sensor mounted on the vertical backbone. By design we made sure the motor and the mechanism would not produce enough torque to turn the instrument round fully, as this would be detrimental to the wiring. A selection of built-in lights in different colors (white, blue and red) have found a place in the instrument as well.

Complete circuit drawings can be found on the Logos webpage. It's all open source, such that other people can freely use our designs and eventualy improve on them.



The <Klar> robot can be controlled such as to perform classical pieces (Debussy's 'Premiere Rhapsody' is a good example) in a quite convincing way. However, realizing this, involves a lot of work from the side of the programmer, since all details with regard to expression have to be translated into appropriate controller commands. Seen in the group of monophonic wind instruments designed and build sofar, <Klar> is doubtless the most flexible instrument. The wealth of controllers make it possible to program the instrument such as to sound sounds completely unlike what we expect clarinets to be capable of doing. It can easily surpass the possibilities of human players but at the other hand, human players can produce sounds that this robot is not yet capable of producing, such as some multiphonics and vocal-instrumental interfering sounds.

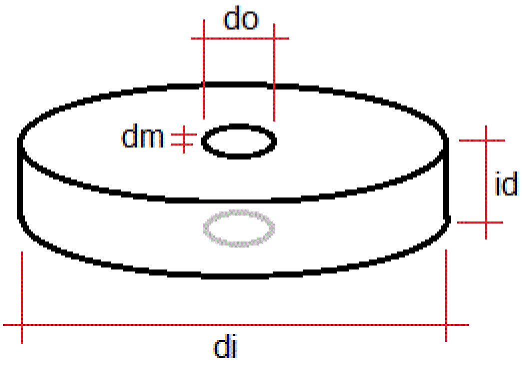
<Whisper>

The <Whisper> robot was designed to be very silent and bears no ressemblence to any existing instrument. It's sound production is based on the cavity resonator, a somewhat strange device known in acoustics. In daily life people may have run into such sound generators as they are often used as a whistle on some water cookers. They find extensive applications in bird calls of different kinds and in quite a few toys (rubber ducks) and simple toy instruments. All these are designed to be blown (or suck) with the mouth. From an acoustical point of view cavity resonators at first sight appear to be Helmholtz resonators: there is a cavity of air and two orifices on opposing sides of the cavity. However, the math around them developed by Herman Helmholtz around 1860 and later refined by Walter Rayleigh does not seem to apply here. Properly speaking a Helmholtz resonator ought to have a single well defined resonant frequency lacking overtones, whereas the cavity resonators under consideration here, operate over a range of more than an octave and produce a manifold of non-harmonic sounds and noises, including multiphonics. The main reason for this behavior seems to be that our resonators are driven by turbulent air of very low pressure and hence the dominant sounds produced are edge tones around the orifices. It is known from organ pipes that the frequencies of these edge tones are highly dependent on applied wind pressure.

We started off by constructing a wide variety of cavity resonators. Small flat cans gave good results and had a quite wide pitch range under varying pressure conditions. The addition of a conical of even cylindrical secondary resonator increased the sound level quite a bit, although it greatly influences (and limits) the pitches obtainable. After a lot of experimentation we decided to construct these conical resonators with the large end cut under an angle of 45 degrees, this to make the resonant frequency less pronounced. These cones were made from a tin-lead alloy as used for organ pipes. The cavity resonators were glued inside the tapered end of the cones. We made stainless steel flanges to mount the resonators and their cones on the windchest.

<Whisper>

cavity resonators with two holes



$$f = 54.11 \sqrt{\frac{1.4142\, do^2}{di^2\ id\ (dm + 1.16\, do)}}$$

$$f = \frac{64.35\, do}{SQR(\ di^2\ id\ (dm + 1.16\, do))}$$

resonant frequency if considered as a Helmholtz resonator.

Sofar we have no sound explanation for the observed wide difference between calculated and measured resonances. We might assume turbulencies play a major role here, and likely the velocity of sound, taken as a constant in the above calculation cannot be considered constant. This was verified by measurement. The differences are substantial, but apparently not large enough to thoroughly explain our mystery...

Small Sunon fans used for cooling components were used to provide airflow. We had assembled quite a lot of them over the years as in our designs for instruments we systematically removed fans from circuits, for they make a lot of extraneous noise. These little fans work on a 12 V DC voltage but they easily can withstand 16 V as we found out. They typically produce turbulent air at very low pressure.It should be noted that this instrument works on suction wind! We have no clue as to what explains the fact that suction wind works better, given the inherent symmetry of the resonators.

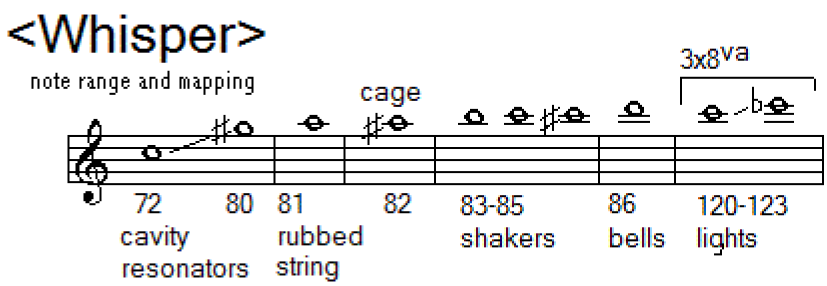
From an electronic point of view, driving 8 small DC motors is a problem we already encountered and solved at the time when designing and building our <Sire> robot. Hence we could use the same microcontroller board in this project. The circuit using a single 18F2525 PIC microcontroller as well as four dual H-driver chips can be found on the webpage describing the <Sire> project. However, as things turned out, the firmware for that board, using only a single PIC processor, caused audible PWM based artifacts from the fan motors. In the <Sire> project, this came unnoticed as the sirens are pretty loud themselves. Thus we decided to design a new PCB from scratch. As our favorite PIC controllers have only two hardware PWM outputs on board, we used four microprocessors to steer eight fan motors. Thus is became possible to use above-audio frequencies for the PWM and getting rid of audible artifacts.

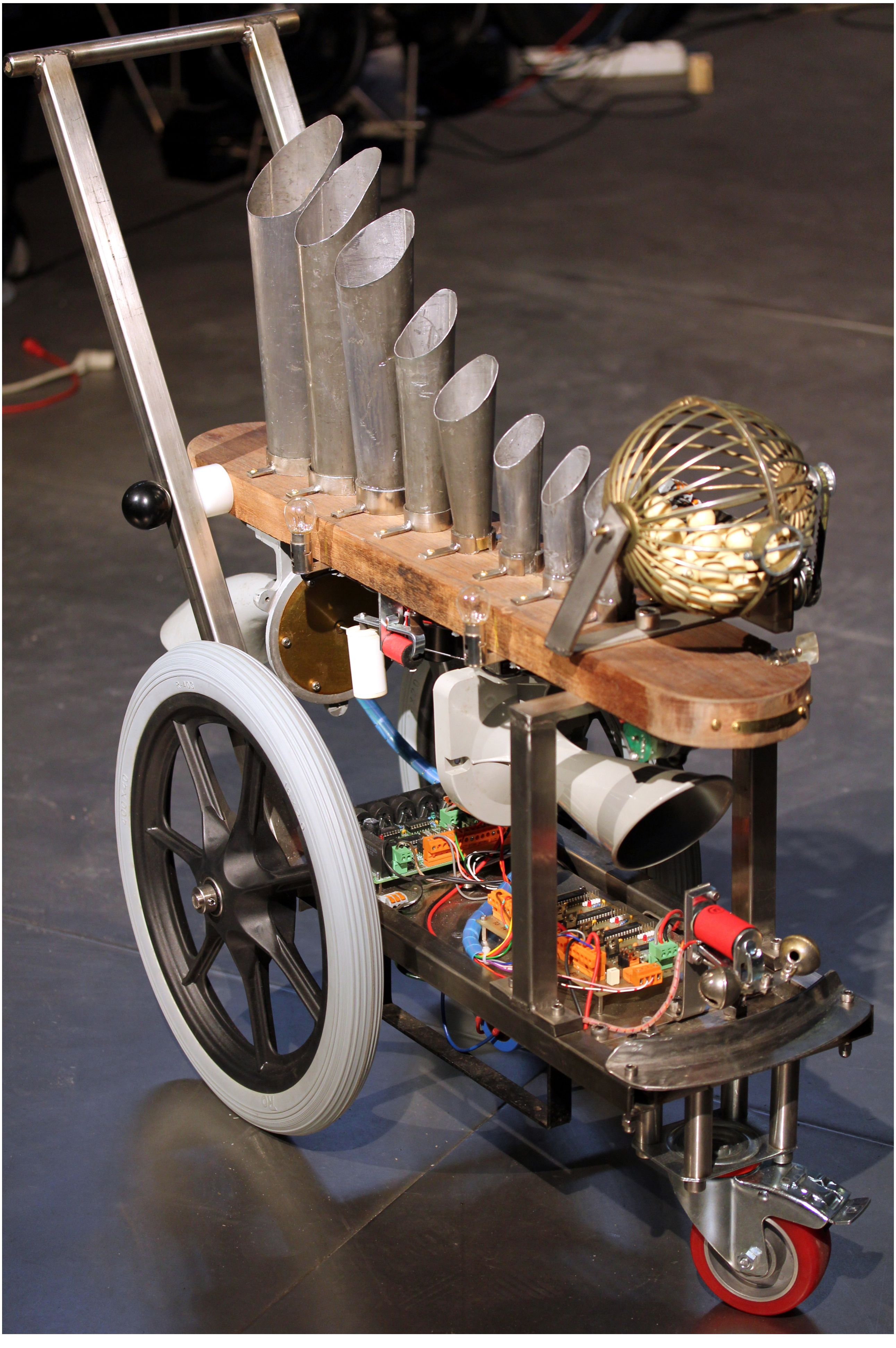
The rubbed string component is based on the same sound generation principles underlying Luigi Russolo's Intonarumori. He used a crank driving a wheel over which a piece of gut string (the tension could be controlled with a hand lever) was led. The other side of the string being attached to a membrane connected to an amplifying horn, a linear cone in most of his instruments. In our design we used a metal membrane coupled to a flared cone taken from an old alarm buzzer. The crank with wheel in the Russolo design, was replaced by a small high torque Johnson motor powered by a variable DC voltage

In <Whisper> we rub the string with a small dented wheel mounted directly on the axle of the motor. Thus excitation is mostly longitudinal and passed to the center of the amplifying membrane. Acoustically one could analyse this as a series of approximate Dirac-pulses upon with the system reacts with its impulse response. The repetition rate of the pulses - a function of the rotation speed of the motor - set aside, there is no real pitch in the sound produced. It is a highly inharmonic noise. The tension on the string changes the spectrum greatly, but does not lead to 'tuning' of any kind. Friction increases of course with increasing force, eventualy leading to stalling of the motor and obvious excessive wear of the string.

The three small shakers on this robot were made from empty 35mm film cans filled with iron or lead granules. The shaking is activated by A.Laukhuff pallet lifting solenoids.

On the front of the robot, we mounted two cast bronze sleigh bells activated by a somewhat larger Laukhuff solenoid. This was designed such that on reception of a note on command, the armature holding the bells will resonate mechanically. The sound of these bells is more or less defined and corresponds to midi note 104 (G#).





Namuda: Gesture recognition at work

Building acoustical robots is obviously only a very partial answer to the fundamental questions we raised in the introduction to this article. In particular, the problem of musicianship was in no way touched upon. Moreover, we have been cheeting the reader a bit in that so far we did describe automated acoustic instruments but left out the real robotic aspect they do have. Lets have a throw at it...

It's a trivial fact that no matter what sound we make, it inherently necessitates motoric action. Our body has to move. No action, no sound. Moreover, the very fact that we move for making sound, is what makes attendence to a live concert performance into a meaningfull ritual. Long before we started the project of the robot orchestra, we developped a system capable of detecting body motion and gesture using Doppler sonar as well as radar technology. The 'invisible instrument' is a completely wireless system based on detailed analysis of reflected waves by the naked human body if exposed to ultrasonic or microwave radiation. The recognition software is largely based on fuzzy logic for classification of gesture properties. A defined set of about twelve expressive gestures can be recognized. Namuda dance technique [3] requires a mutual adaptation of the performer and the software parameters. In order to make the study of Namuda dance possible, we have designed a series of études in which each single gesture prototype can be practised. Since visual feedback to the performer is very problematic in the context of performance, for it greatly hinders freedom of movement and is by nature too slow, we have opted for auditory display. The robot orchestra as we have designed and built it, makes a good platform for such auditory display, particularly since the sounds are not virtual (loudspeakers) but real acoustic sounds emanating from real physical objects. In fact just about any musical instrument can be seen as an example for auditory display as it by its very nature truthfully converts a certain subset of fine motor skills and gestures into sound. The gestures underlying music practice may very well constitute a basis for the embodiment underlying the intelligibility of music. [5] The motor skills and gestures entailed by playing traditional musical instruments are obviously instrumental in nature. They are dictated by the mechanical construction of the instrument. Therefore, as an extension of the body, an instrument can, at most, be a good prosthesis. By removing the necessity of a physical object, the body becomes the instrument. But this in no way removes the need for motor skill and gestural control.

1. Namuda études and recognisable gesture prototypes

Each gesture prototype is mapped to a different subset of responding robots. In this respect, the study of Namuda gestures is quite similar to the study of any musical instrument. A certain level of fine motor control has to be developed in the player. Only once that level has been reached can the recognition software be modified by changing the parameters slightly. One would never buy a new and better violin for a child every time it makes a handling and playing mistake. Only once it knows the basics reasonably well should buying a better instrument become an option. Fortunately, in the case of the invisible instrument, we do not have to buy a new instrument but we can improve the software and adapt it to the player. This last possibility opens a whole new perspective for future developments in instrument building.

- Speedup
- Slowdown
- Expanding
- Shrinking
- Steady
- Fixspeed
- Collision

- Theatrical Collision
  Smooth (roundness)
- Edgy
- Jump (airborneness)
- Periodic
- Freeze (no movement)

Parallel to these recognition-based gesture properties, the implementation also offers a full set of very direct mappings of movement parameters on sound output:

- moving body surface: The most intuitive mapping for this parameter seems to be to sound volume or density.

- speed of movement: The most intuitive mapping for this parameter seems to be to pitch.
  - spectral shape of the movement: The most intuitive mapping for this complex parameter seems to be to harmony.

- acceleration of the movement: The most intuitive mapping for this parameter seems to be to percussive triggers.

Of course there is nothing mandatory in the way the mappings of gestural prototypes have been laid out in these études. It is pretty easy to devise mappings more suitable for use out of the context of our own robot orchestra. The simplest alternative implementations consist of mappings on any kind of MIDI synth or sampler. However mapping the data from our gesture recognition system to real time audio streams (as we did in our 'Songbook' in 1995, based on human voice sound modulation via gesture) is an even better alternative.

2. Extending the time frame

The gesture prototypes practised in the études reflect a gestural microscale in the time domain. Their validity may be as short as 7ms and can for most properties seldom exceed 2 seconds. The only gesture properties that can persist over longer time spans are freeze, periodic, edgy, smooth, fluent and fixspeed. Some can, by their nature, only be defined over very short time intervals: airborne and collision. These gesture prototypes are to be compared to what phonemes are in spoken language, although they already carry more meaning than their linguistic counterparts. Meaning here being understood as embodied meaning.

By following assignment and persistence of the gesture prototypes over longer time spans, say between 500 ms and 5 seconds, it becomes possible to assign expressive meanings to gestural utterances. Here we enter the level of words and short sentences, to continue using linguistic terminology as a metaphor. When we ask a performer to make gentle movements in order to express sympathy, then the statistical frequency of a limited subset of gesture properties will go up significantly. When we ask for aggression, the distribution will be completely different.

3. Relation to other dance practices.

Although as soon as we gained some insight in the potential for dance offered by our technology – in the mid nineteen-seventies – we carried out artistic experiments with dancers trained in classical ballet as well as modern dance, we quickly found out that such an approach to dance was unsuitable to work well with this technology. Classical dance forms concentrate on elegance and – in general – avoid collision and a sense of mass. Position in space and visual aspects are very dominant. Immediately alternative dance practices came into consideration. In the first place butoh dance, an avant-garde dance practice with its roots in Japan, where we also came in contact with it (through

Tari Ito). Thus we got in contact with dancers such as Min Tanaka, Tadashi Endo and Emilie De Vlam. This has led to quite a considerable list of collaborative performances. However, butoh is only vaguely defined from a technical dance point of view. Its non-avoidance of roughness, its nakedness [6] and its concentration on bodily expression, leaving out any distracting props and requisites, formed the strongest points of attraction. Only in some forms of contact improvisation did we find other links, but in this dance form we ran into problems with our technology, which is not capable of distinguishing the movements of more than a single moving body at the same time. As far as couple dances go, we have also investigated tango, in part also because we happen to be a tanguero ourselves. In this type of dance the problem of the two inseparable bodies poses less of a problem since movements are always very well coordinated.

4. Interactive composition and choreography

It will be clear that the mastering of Namuda opens wide perspectives for the development of real time interactive composition with a strong theatrical component. Over the 40 years that we have been developing the system, many hundreds of performances have been staged.

The entire Namuda system including the invisible instrument as well as the robot orchestra is open for use by other composers and performers. Scientists interested in research into human gesture are also invited to explore the possibilities of the system.

There is still a lot of work left to be done on improvements on the robots, the hardware and recognition software as well as in terms of its artistic implementations. An open invitation.

Godfried-Willem Raes

Endnotes

[1] The complete hardware description of the system can be found at: http://www.logosfoundation.org/ii/Holosound_ii2010.pdf. The background to our experimental instrument-building projects is largely taken from “An Invisible Instrument”, Godfried-Willem Raes, 1997: http://logosfoundation.org/g_texts/invisins.html, which deals in greater depth with the philosophy behind the design.

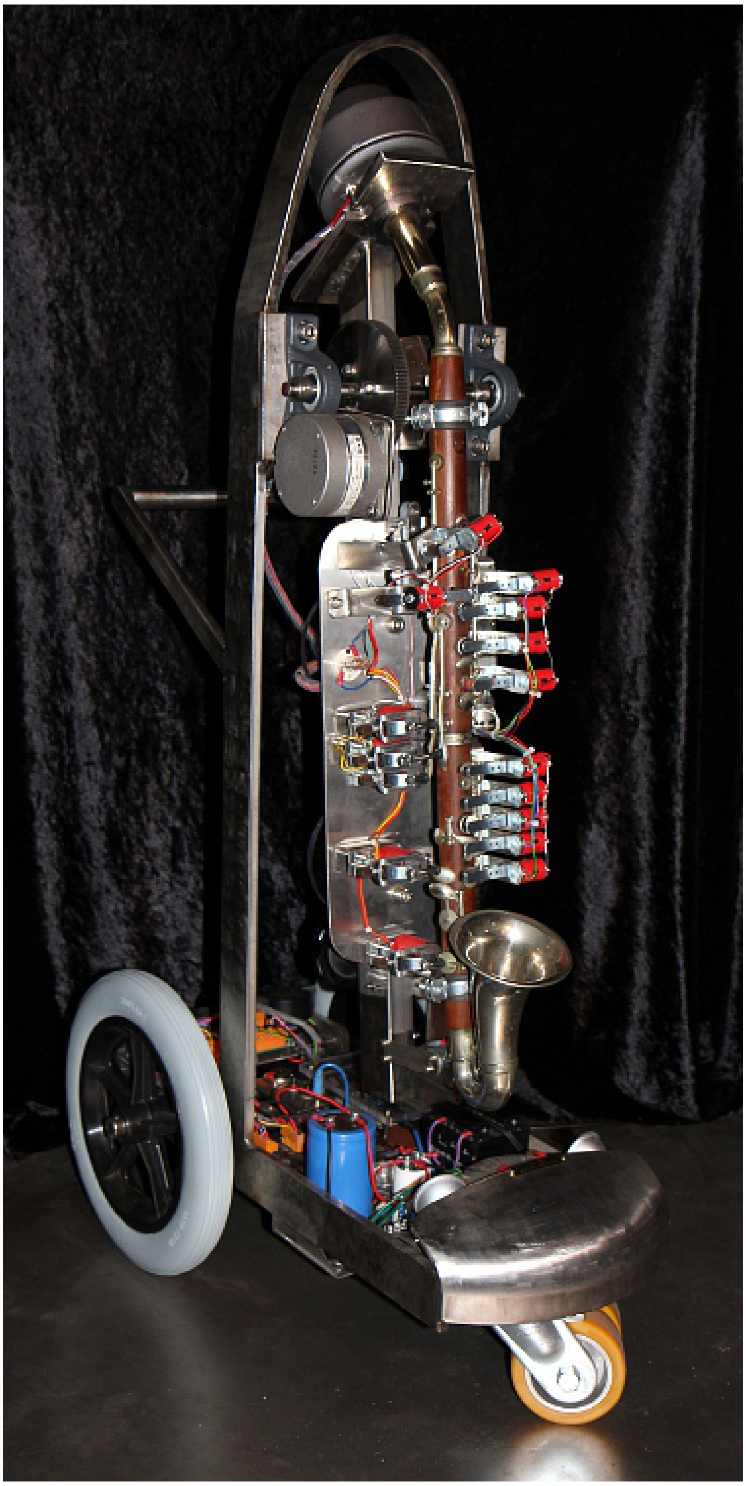
[2] The software gesture recognition layer is decribed in full in this paper: http://www.logosfoundation.org/ii/Namuda_GestureRecognition.pdf

[3] Namuda is a word of our own casting and stands short for 'Naked Music Dance'.

[4] Detailed information on the robot orchestra and all robots constituting it can be found at http://www.logosfoundation.org/instrum_god/manual.html

[5] These matters were discussed in depth in my texts on the invisible instrument: Raes,1993 ,1994 and 1999.

[6] We wrote an essay on nakedness some time ago, after realizing that even nowadays there are still people around that seem to have difficulty in coping with this... The text can be read at: http://logosfoundation.org/g_texts/naked.html.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