Distance Sensing

devices for wireless distance and position determination usefull as gesture controllers for robotic musical instruments

by

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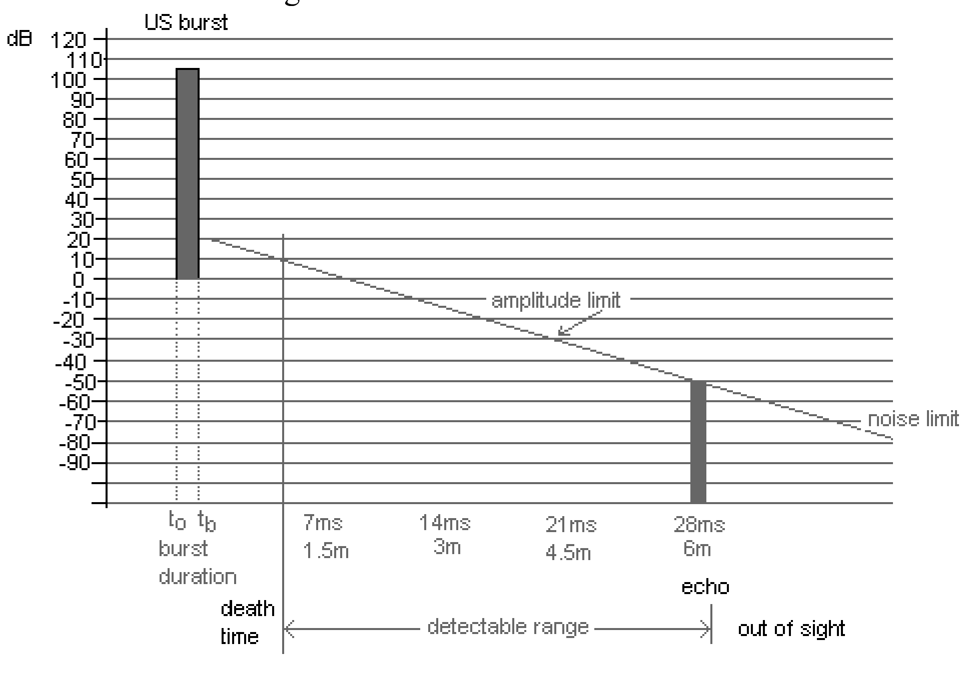
Since the early seventies we did build sonar devices to control our self made analog electronic music synthesizers. In those years, simple to use transducers were not readily available on the electronic component market and so, we had to make our own, based on designs used for underwater hydrophones. (Quarz crystals, inductive devices, self made condensor microphones etc...). Although the focus of our research later on became doppler based sonar and radar movement detection and gesture analysis, we always had quite a few pulsed sonar devices at hand. The easiest and cheapest ones to build nowadays make use of the commonly available 40kHz transducers. Two approaches are possible: either one uses a single transducer as an emitter for a periodic burst of sinewaves and that then is switched to microphone mode and connected to the input of a voltage controlled amp (preferably a logamp, compensating for the square law decay of amplitude with distance). The time between the start of the burst and the reception of the first echo is a linear function of the straight distance from the tranducer to the reflective object or body.



Sonar ranging principle signals

This design can be highly simplified as well as significanty improved in terms of response time by using two separate transducers tuned to the same frequency, one used as burst transmitter and the other one, placed in close proximity, as receiver. Send - receive control can easily be confined to even the simplest microprocessor. Even before the advent of microcontrollers, we did it using nothing but discrete logic chips, a timer and some analog circuitry. Better results than those obtained with these 40kHz piezo transducers can be achieved using the popular Polaroid capacitive sensor, working on 50kHz. This sensor however requires a very high polarising and high driving voltage (300V burst). Because the diaphragm is pretty large (ca. 50mm), the sensor is very directional and narrow beam.

The sampling rate, the shortest possible time between individual distance measurements in all ultrasonic distance sensors is determined by the velocity of sound (ca. 340m/s, although the velocity of sound in air decreases for very high frequencies). This dictates that say for a measurement distance of 3 meter, the time between measurements has to be much larger than 18ms. For single transducer devices this time has to be increased with the required death time between measurements required to discharge as well as damp sensors and for resetting the operational conditions of the input circuitry. Thus the Polaroid sensor is incapable to offer you more than ca 5 measurements a second. Although all of these transducers give out distance data, it is technically very well possible to gather also information on the size of the reflecting surface, since this is proportional to the amplitude of the received echo. This parameter however can only be reliably used if the reflective properties of the surface are not subject to changes between measuments as is usually the case with clothed bodies. This is one of the reasons why all our experiments, artistic presentations and measurements are done using naked bodies. Another very obvious reason is that clothing damps the amplitude of the reflected echo with a factor ranging between -8dB to -18dB as compared to a naked body.

It will be clear that this ranging technology alone is not suitable for acquiring information on gesture or even on pretty slow body movement. The minimum required sampling rate to untertake this would be ca. 128 samples a second, way above even what can be achieved with normal video cameras sampling at 24 to 30 frames a second. (Raes, 1993). Trigonometric infrared distance sensors (4) as well as radar sensors being the optimum choice for fast position and gesture tracking.

However, slow distance measurement comes in handy as a complementary information source in any doppler based radar or sonar system. For some 'popular' instruments such as the Theremin, it is even mandatory. Nevertheless, for a good theremin, response time has to be very fast indeed, dictating the use of either radiofrequency or light based technologies.

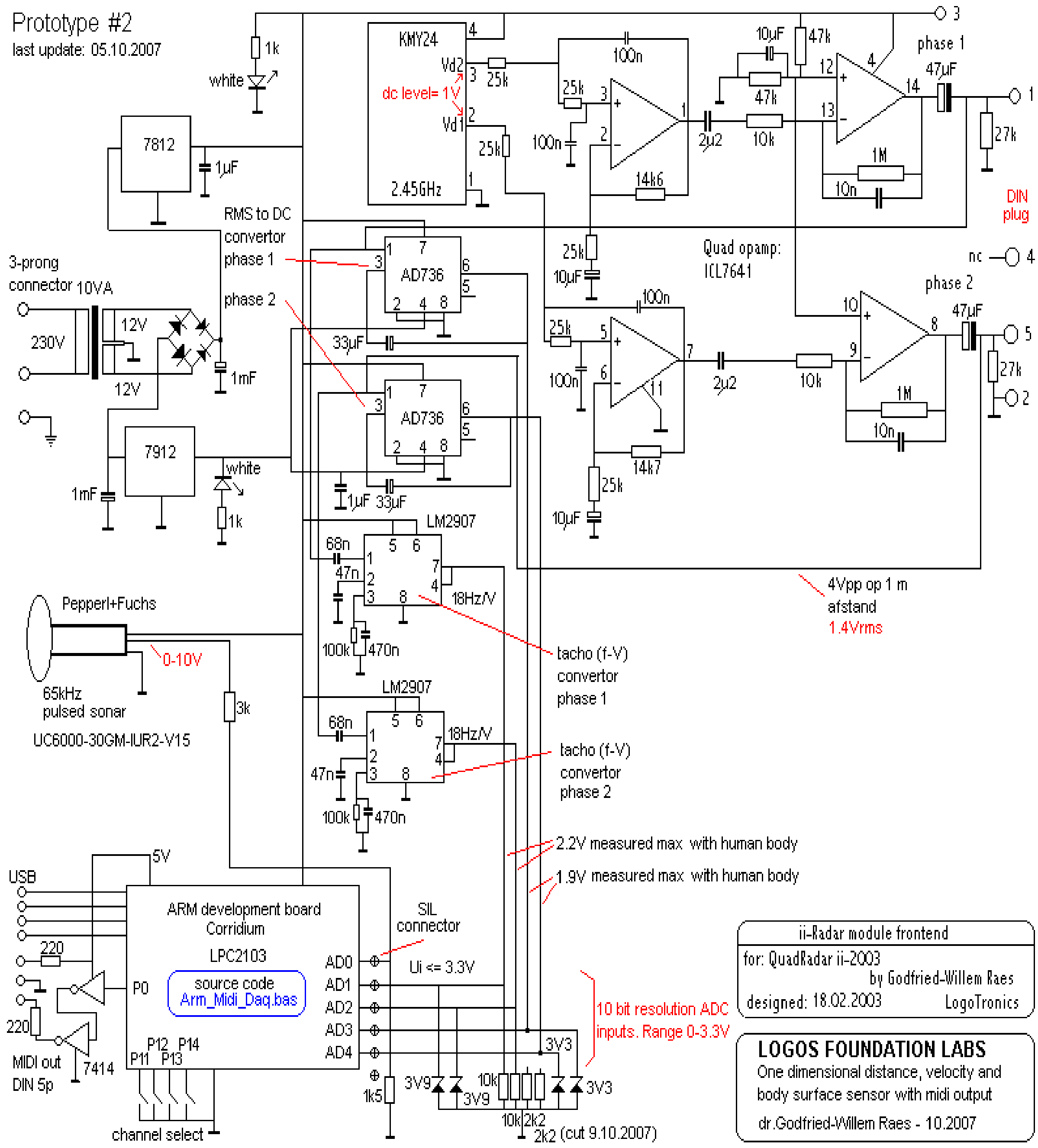
Despite the inherent slowness of ultrasonic distance measurement, we never stopped our investigations into these technologies. Doppler sonar and radar systems lack the possibility of easy distance determination, and so, a hybrid combination of sonar ranging with doppler radar seems very promising. We do not combine pulsed sonar and doppler sonar, since this always leads to mutual interference. Since a few years, a few long range proximity sensors became available. One of these is the Pepperl+Fuchs UC6000-30GM-IUR2-V15, which we used in an evaluation project in the context of our robotic M&M orchestra. This distance sensor claims a measurement range between 350mm and 6000mm, for a reflective surface of minimum 100mm x 100mm. It gives out an analogue voltage between 0 and 10V linearly proportional to the distance. The operational range can be programmed (limited) on the device itself. Temperature compensation is part of the design of this transducer. The ultrasonic operational frequency is ca.65kHz. The sampling rate, identical to the burst frequency is (our own measument) 7.06 S/s. This sensor suffers from the same deficiency as just any design in ultrasonic distance measurement we know off: it produces an audible clicking noise synchronous with the burst frequency. Fortunately, the noise level for this transducer is a lot lower than that for the Polaroid sensor. If the sonic environment in which it gets used in loud enough and if it has a reasonable amount of high frequency components in the spectrum, it will be easily masked.

The distance resolution in itself is quite impressive with 0.35mm over a range of 4000mm. This specification alone dictates the use of an ADC with minimum resolution of 14 bits. Evidently, if one uses a setup consisting of more than a single transducer, it becomes possible to acquire information on the precise position of an object or body in a space. To this purpose, the sensors are equiped with synchronisation and sequencing possibilities. This of course at the detriment of sampling rate, since timing requires the transducers to wait for each other. Only the cost of using an array of these Pepperl+Fuchs transducers becomes prohibitive.

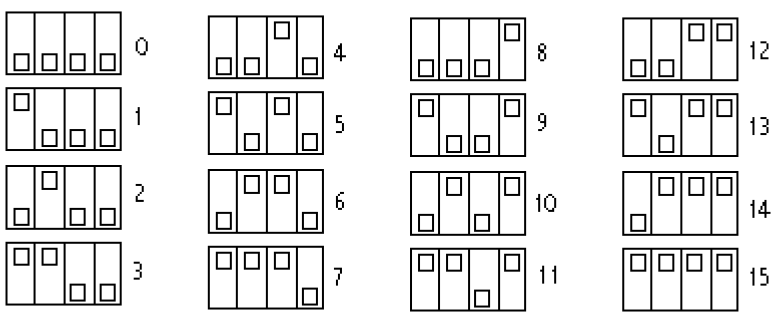
HY1

A first laboratory version of a hybrid sensor was developed using a 32 bit ARMmite development board, programmable in Basic. It has a USB port for programming and debugging. The ARM processor is an LPC2103 in a tiny LQFP-48 package clocked at 60MHz. This system has 8 channels of on board ADC with a conversion speed of 6µs. Resolution however is only 10 bits, as usual on nowadays microcontrollers. The pins can be programmed for serial communication on the baudrate required for MIDI (31250). However, since the board runs on 3.3V, some level shifters are required to drive the midi output. To make the project a complete sensing system for body movement we added one of our existing quadrada radar frontend modules to the prototype design, such that we now can gather information on distance, velocity of movement perpendicular to the axis as well as body surface. Since the radar device is a two phase type (a Siemens KMY24, operating on 2.4GHz) , we can also discriminate approaching and recessing movements. By calculating the phase angles between the two amplitude channels and the two tacho channels, we can derive information with regard to the aspect ratio of the moving body as well as to the movement angle of the fast movements. The data is send out as a midi stream of polyphonic key aftertouch messages. (160 + channel, followed by two 7 bit data bytes: msb, lsb). The two data bytes - seven bits each, as dictated by the midi standard, pack the information as follows: the 3 low bits of the high nibble of the msb give the AD channel (0-4), the low nibble of the msb gives the 3 most significant bits of the data, whereas the LSB completes the data with the lowest 7 bits to a full 10 bit value.

The complete schematic for the hybrid one-dimensional transducer unit is depicted below:

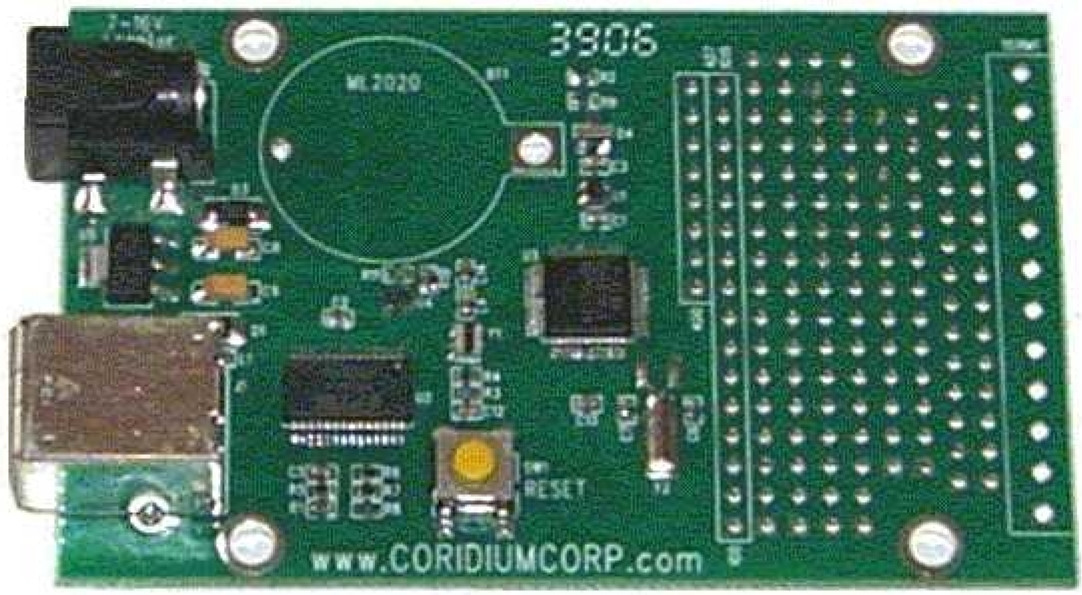


The midi channel used to transmit the data can be set with the dip switches on the ARM board:

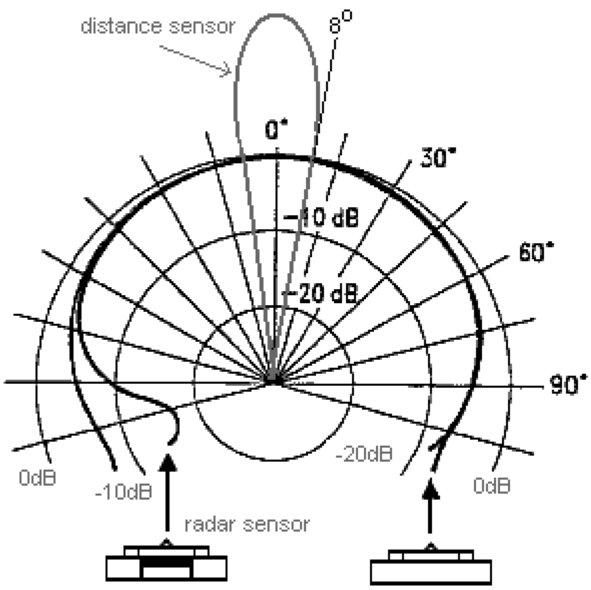


DIP-switch setting for midi-channel

The ARMmite development board we used looks like:



When the distance sensor is able to return valid data, we return a value for the size of the surface of the moving reflective surface independent from the distance. This is calculated according to surface = (distance ^2) * amplitude. Note that information for surface corresponds to the amplitude of the signals received by the radar. If the distance is undeterminable by the sensor, in which case it will output either zero or maximum, the value returned for the surface will be uncertain and will reflect only the amplitudes as received by both phases of the radar sensor alone. The radar-based movement velocity values returned are independent from the distance. However, since the distance sensor is one-dimensional, the value cannot be corrected for the angle of the movement. (doppler frequency = speed * COS(angle)) Thus, the movement velocity value can only be relied on if taken between two valid values of distance, since in that case we may assume a movement in axis with the line of sight of the sensor. Note that there should always be a free line of sight (with no obstacles) with an opening angle of 8 degrees in the range up to 6 meters from the sensor. The angle and phase information can only in very specific cases, requiring information on the gestures not retrievable with the sensor, be used to correct the speed information. The polar diagram for the sensor combination clarifies this.



Polar diagram for the HY1 sensor combination

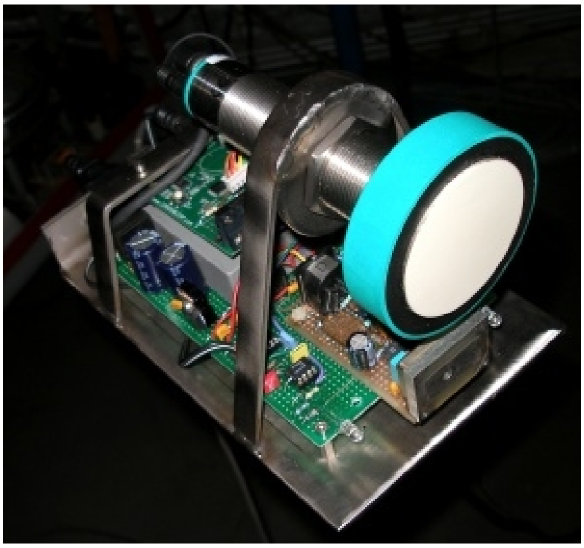
The tested and functional prototype firmware for the ARM 32-bit processor written in ARM-Basic [can be downloaded: Arm_Midi_Daq_HY1.bas](Arm_Midi_Daq_HY1.bas).

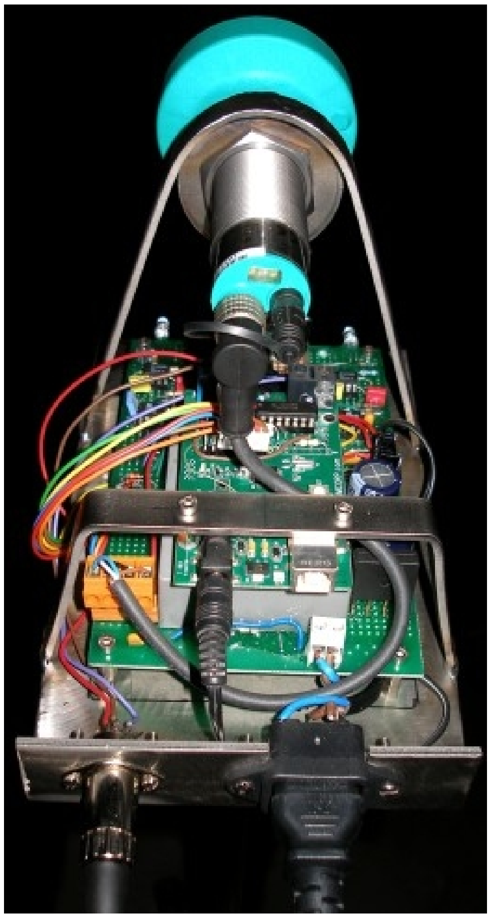
This firmware outputs each datachannel at a steady rate of 10S/s, so the data burst frequency becomes 50 midi aftertouch messages a second. Oversampling on the radar channels is applied internaly. The tacho channels are (over)sampled at 40S/s and the surface channels at 20S/s. The data result of these channels is an integrated value over the number of samples taken. The conversion of the distance data (note that the distance sensor samples only at ca. 7S/s) to slow movement axial speed expressed in m/s can be derived as:

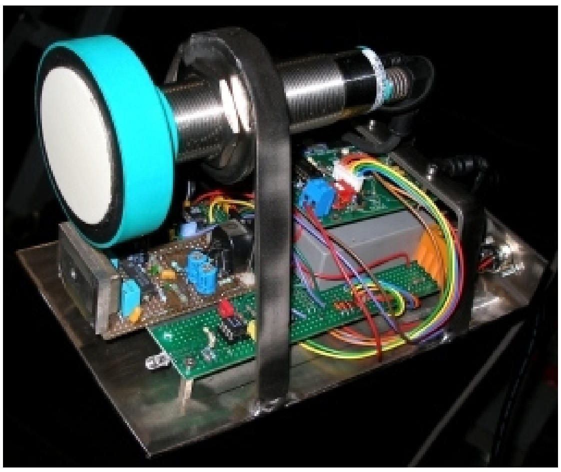
v = 7 * (d(t0) - d(t2)) / 255.25

This of course only in the case that the databuffer contains at least 3 valid values for the distance. Practical values fall within the range -4.22m/s to + 4.55m/s. The sign of the value reflects the direction of the slow movement: towards the sensor when positive and away from the sensor when negative.

The prototype assembly of the hybrid sensor, baptized HY1, was realized on a sturdy TIG welded stainless steel chassis, with a 3/8" thread at the underside such that it can be mounted on a microphone stand. There are just two connection wires: one for mains power and one for the midi output. The large round component in top is the Pepperl+Fuchs transducer. Under it and assembled in-line, we see the KMY24 Siemens radar sensor. The completed sensor construction can be seen on the pictures following.







In the definitive circuit, we will use a PIC microcontroller to convert the analogue signal from the Pepperl+Fuchs sensor to a stream of UDP/IP messages via a network driver. This way, the sensor can be placed just about anywhere a network connection is available and the data can be received by any connected computer. The protocol we use is an adapted and extended form of MIDI: device id, status byte, controller, data.

HY2

A second project on similar lines (baptised HY2), makes use of a distance sensing device produced by Honeywell. The type number is 944-T4V-2D-1C1-130E. The scan range is limited to 3.5m and the output is available as a 0-10V analog voltage. The ultrasonic operational frequency is 130kHz and the beam angle 8 degrees. Response time -after the data sheet- is 120ms. We will report further on this project as soon as completed.

The new devices are being developed by a team consisting of myself, Johannes Taelman (PIC coding and development) and Kristof Lauwers (application software layer).

Artistic applications

- Godfried-Willem Raes "Hybrid Sensing Study #1" (2007)
- Godfried-Willem Raes "De weg, Der Weg, The way" (2007), an act in 'Technofaustus'
- Kristof Lauwers "Zy 1" (2007)

We are develloping a series of studies and demonstrations to be performed by a naked performer, in which we try to explore different ways of mapping the sensor information (alone or in combination with either the sonar or radar version of our invisible instrument) on musical activity produced by our robot orchestra, composed of following robots:

- <Player Piano>, an automated piano
- <Harma>, an automated harmonium
- <Piperola>, automated treble pipe organ using flue pipes
- <Bourdonola>, automated bass pipe organ using wooden pipes
- <Vox Humanola>, automated pipe organ using vox humana reed pipes
- <Troms>, an automated series of 7 drums with 24 beaters
- <Rotomoton>, five automated rototoms
- <Flex>, an automated set of singing saws
- <Thunderwood>, automated percussion
- <Springers>, automated large spring, shakers and siren
- <Dripper>, automated rain machine
- <Vibi>, automated vibraphone
- <Belly>, an automated carillon made of shipbells
- <Klung>, an automated brass angklung
- <Autosax>, an automated saxophone
- <Tubi>, an automated quartertone tubophone
- <So>, an automated sousaphone
- <Puff>, an automated percussive quartertone organ
- <Trump>, automated low trumpet organ register
- <Hurdy>, an automated hurdy gurdy.
- <Ake>, an automated accordion.
- <Llor>, an automated carillon made with stainless steel shells.
- <Sire>, an automated assembly of 24 motor driven sirens.
- <Vacca>, an automated collection of 48 cow bells
- <psch>, an automated set of 12 small thundersheets
- <Krum>, an automated organ register (Cromorno).
- <Snar>, an automated snare drum
- <Vitello>, an automated set of 36 cow bells

- <Bako>, an automated bass accordion
- <Qt>, an automated quartertone pipe organ
- <Xy>, an automated quartertone orchestral xylophone
- <Casta Uni> & <Casta Due>, two robotic castanet players

Everytime we finish a new robot and add it to the M&M orchestra, we add a new chapter in this suite of pieces.
The sensor and signal conditioning circuit is available for any competent composer wanting to develop a piece or performance using it. Since the use of the instruments requires software to be written, it is highly advisible to study our <GMT> software and its functionality with regard to this instrument. As an alternative, the public domain language PD can be used as well. Usefull PD patches are being developed by our collaborators Kristof Lauwers and Johannes Taelman. They will be available upon demand. This device can be used in combination with our PicRadar sensors operating on 9.5GHz as well as with a set of Quadrada sensors operating on 2.4GHz.

Notes:

(1) This project is part of the ongoing research of the author in gesture controlled devices over the last 30 years. Earlier systems, based on Sonar, Radar, infrared pyrodetection and other technologies are fully described in "Gesture controlled virtual musical instrument" (1999), in "Quadrada" (2003), "picradar" (2004) as well as in his doctoral dissertation 'An Invisible Instrument' (1993). Artistic productions and compositions using these interfaces and devices have been: <Standing Waves>, <Holosound>, <A Book of Moves>, <Virtual Jews Harp>, <Songbook>, <Slow Sham Rising>, <Gestrobo>, <Technofaustus> , "PicRadar Studies" etc. The research is since 2005 supported in part by the Ghent University College (Hogent).

(2) People interested in buying the sensors as described here (fully functional and inclusing the programmed PIC or ARM processor) can take contact with the author. Cost, depending on the version required start at 2200€ for a single transducer.

(3) Microcode for the PIC in the UDP/IP version of this project is being written by Johannes Taelman.

(4) The Sharp infrared sensor (Type GP2Y0A02UYK)b with a range of 20cm to 150cm samples distances only at a pace of 18.8Hz to 29.67Hz and would be a bad choice here. It also has a lot of other deficiencies, such as very high glitches on its analog outputs during data changes. We did apply it in our bass-accordeon robot <Bako>, and more details and experiences can be found on our webpage on that project.

(5) A short introductory note in dutch on this sensor project in txt format can be downloaded. It was published in the november issue of the magazine 'Logos Blad'.

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