The Hands: The Making of a Digital Musical Instrument

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Abstract: Michel Waisvisz's The Hands is one of the most famous and long-lasting research projects in the literature of digital music instruments. Consisting of a pair of data gloves and exhibited for the first time in 1984, The Hands is a pioneering work in digital devices for performing live music. It is a work that engaged Waisvisz for almost a quarter of a century and, in turn, has inspired many generations of music technologists and performers of live music. Despite being often cited in the relevant literature, however, the documentation concerning the sensor architecture, design, mapping strategies, and development of these data gloves is sparse. In this article, we aim to fill this gap by offering a detailed history behind the development of The Hands. The information contained in this article was retrieved and collated by searching the STEIM archive, interviewing close collaborators of Waisvisz, and browsing through the paper documentation found in his personal folders and office.

> *. . . it was very restrictive and very difficult too . . . but it was a huge lesson!*
> —Michel Waisvisiz, 24 April 2007

Michel Waisvisz (1949–2008) was a composer, inventor, and music technologist. He is best known as the inventor and performer of The Hands, a pioneering digital musical instrument (DMI) made of two data gloves that enabled him to create and control elements of a musical performance in real time. His work was conducted at a time where a number of DMI projects were being developed at the Studio for Electro-Instrumental Music (STEIM) in Amsterdam (Ryan 1991; Waisvisz, Ryan, and Collins 1993; Wanderley, Battier, and Rovan 2000; Miranda and Wanderley 2006) and an approach was emerging where effort and expression were linked to become a central design guideline (Ryan 1992). Waisvisz's performances with The Hands have inspired generations of music technologists, researchers, live performers, and the diverse audience of the New Interfaces for Musical Expression (NIME) community that Waisvisz himself helped to establish in 2001. Although the development of The Hands engaged the composer relentlessly for 25 years of his life, little in the way of documentation or records of this effort is available. Waisvisz believed that the magic of a performance can be communicated only live, not in a recording (Waisvisz 1999). Faithful to this credo, he recorded and published only a few works in the later years of his life. Preferring to work as an artist, rather than as an academic, he neither wrote about nor documented his work in detail in a scholarly setting. Even the text documentation retrieved from his archive is scarce and fragmented. It is clear that Waisvisz's attitude towards restless, cutting-edge experimentation and artistic creativity made him see the work of archival as a tedious job to always be postponed to a later date. Still, The Hands remains one of the most-cited and most-famous works in the DMI literature.

The aim of this article is to provide detailed insight into The Hands and the history of its development. The information contained in this article was retrieved and collated by searching the STEIM archive, interviewing Waisvisz's closest collaborators, and browsing through the paper documentation found in Waisvisz's personal folders and office. We are grateful to Andreas Otto for his collaboration with Kristina Andersen in sorting through this vast collection of material. We do so,

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Table 1. Summary of Sensors Used in Each Version of The Hands

	Version 1		*Version 2*		*Version 3*	
	Left	*Right*	*Left*	*Right*	*Left*	*Right*
Momentary push keys	19	17	25	25	30	30
Mercury switches	4	4	4	4	4	4
Ultrasonic receivers	1	–	3	–	3	–
Ultrasonic transmitter	–	1	–	1	–	1
Clip cardioid microphone	–	–	1	–	1	–
Pressure sensors	–	–	2	1	2	2
Potentiometer	–	1	–	–	1	–
Four-character display board	–	–	–	1	–	1

acknowledging that it is difficult to summarize 25 years of work in a short article. In that regard, we invite the interested readership to complement the reading of this article with the online version of Waisvisz's archive, which is currently being updated at http://crackle.org. This article is not aimed at addressing the artistic praxis of Michel Waisvisz. As a consequence, we have left much of the detail of this process for future publications. Nevertheless, we hope that this article will offer the interested audience some depth, clarifications, and a historical perspective on the technical work of one the most important pioneers of experimental DMI live performances.

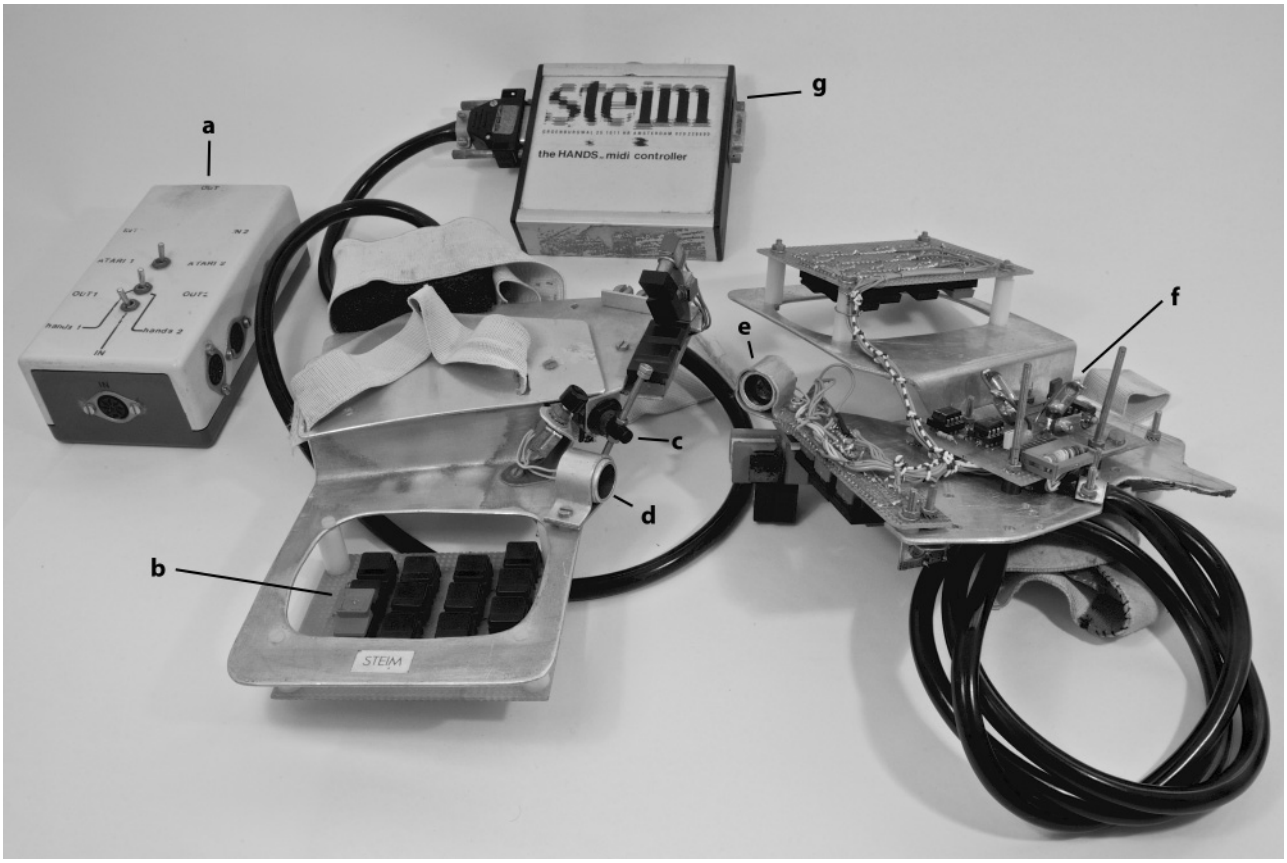
STEIM and The Hands

Michel Waisvisz was a member of STEIM since 1969, and he directed it from 1981 to 2008. STEIM, founded on 27 February 1969 by a group of Dutch composers (Misha Mengelberg, Louis Andriessen, Peter Schat, Dick Raaymakers, Jan van Vlijmen, Reinbert de Leeuw, and Konrad Boehmer) was set up as a research lab for artists to investigate the possibilities of using electronics in the musical domain. It is at STEIM in the early 1980s that Michel Waisvisz began his preliminary research on The Hands, which he would then publicly perform and present for the first time in 1984. The Hands originated from an idea of developing more tactile and immediate ways to approach the creation and manipulation of electronic sounds. Waisvisz was, in fact, a performer with a wealth of experience in theater and live performance that dated back to late 1960s. As such, he found the beauty of sound in its extemporary development rather than in the calculated construction of a recording studio (Waisvisz 2003). The availability of cheaper personal computers and the public release of the MIDI protocol in 1983 immediately opened a wide range of possibilities for the live control of synthesizers. Waisvisz saw the enormous potential that the technology of the time offered, and this gave rise to an intense period of experimentation that engaged him for decades to come. As with probably all projects that manage to have a significant and long-lasting cultural impact, it goes without saying that the results of his effort would have been impossible without the involvement of many artists and engineers. The initial prototype of The Hands was developed by Michel Waisvisz with engineer Johan den Biggelaar, and later improvements were made with the help of Wim Rijnsburger, Hans Venmans, Peter Cost, Bert Bongers, Frank Baldé, Tom DeMeijer, Maurits Rubinstein, Jorgen Brinkman, and David Bristow.

Hardware Development of The Hands

The first version of The Hands dates from 1984. Waisvisz released two more versions of The Hands, in 1990 and 2000. The second and third versions of The Hands presented similar structural design to the first. Each version, however, adopted a different number of sensors, a number that appears to have steadily increased up to the most recent version (see Table 1). In the following section we offer an

Figure 1. The Hands version 1. Right-hand data glove on the left. Left-hand data glove on the right and upside down. Labeled components: MIDI splitter (a), pitch keys (b), potentiometer (c), ultrasonic transmitter (d), ultrasonic receiver (e), mercury switches (f), and MIDI controller (g). (Photo courtesy of Daniel Buzzo.)



overview of the sensor technology implemented in each version of The Hands. This is then followed by a description of the hardware and software developed ad hoc to complement the DMI system.

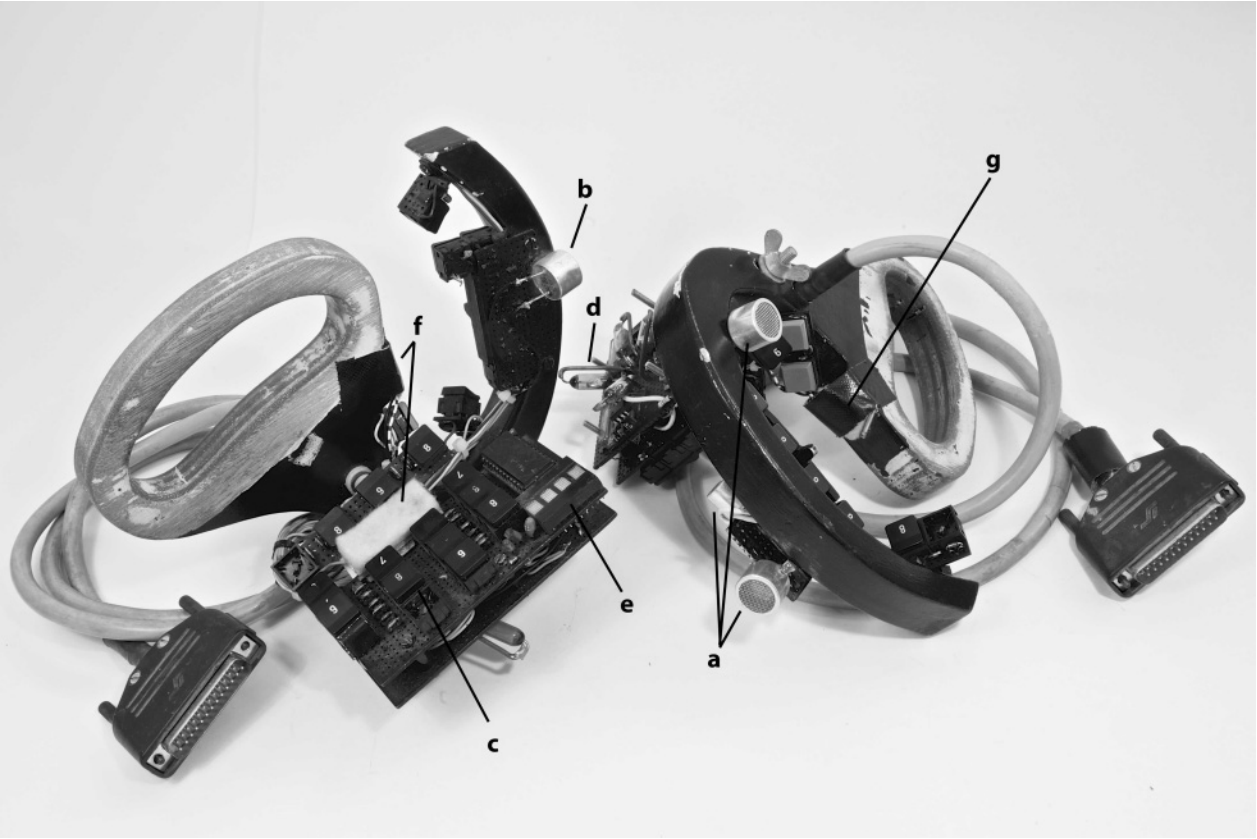
The Hands Version 1

The two data gloves in version 1 of The Hands (1984) were made of two metal plates (see Figure 1). One plate rested on the palm of the hand. On this plate, two elastic bands were attached to wrap and fix the data glove on the performer's hand and wrist. The second metal plate was parallel and slightly lower to the first one. This plate presented features similar to a computer keyboard. Each data glove included the following sensors.

The left-hand data glove had 19 C&K MP01 momentary push keys, 4 mercury switches (tilt switches), and an R40-16 ultrasonic receiver. The right-hand data glove had 17 C&K MP01 momentary push keys, one potentiometer, four mercury switches, and a T40-16 ultrasonic transmitter. Of the 19 keys on the left-hand data glove, 12 were placed in a 4×3 matrix configuration. We will refer to these keys as "pitch keys" throughout this article. Their configuration allowed the index, middle, ring, and little fingers to control three keys in each row. An identical configuration was provided for 12 of the 17 keys in the right-hand data glove. The remaining seven keys for the left hand and five keys for the right were controlled by the thumb of their respective hands. The potentiometer on the right-hand data glove was controlled by the thumb of the right hand.

In 1990, and preceding the development of version 2 of The Hands, Waisvisz worked on the MIDI Conductor, a simplified adaptation of the version 1

Figure 2. The Hands version 2. Left-hand data glove on the right; right-hand data glove on the left. The fingers, except for the thumb, are inserted through the oval structure. Labeled components: ultrasonic receivers (a), ultrasonic transmitter (b), pitch keys (c), mercury switches (d), four-character display board (e), pressure sensors (f and g). The clip microphone is not visible here because, by the time the photograph was taken, the microphone had been removed for use with The Hands version 3. (Photo courtesy of Daniel Buzzo.)

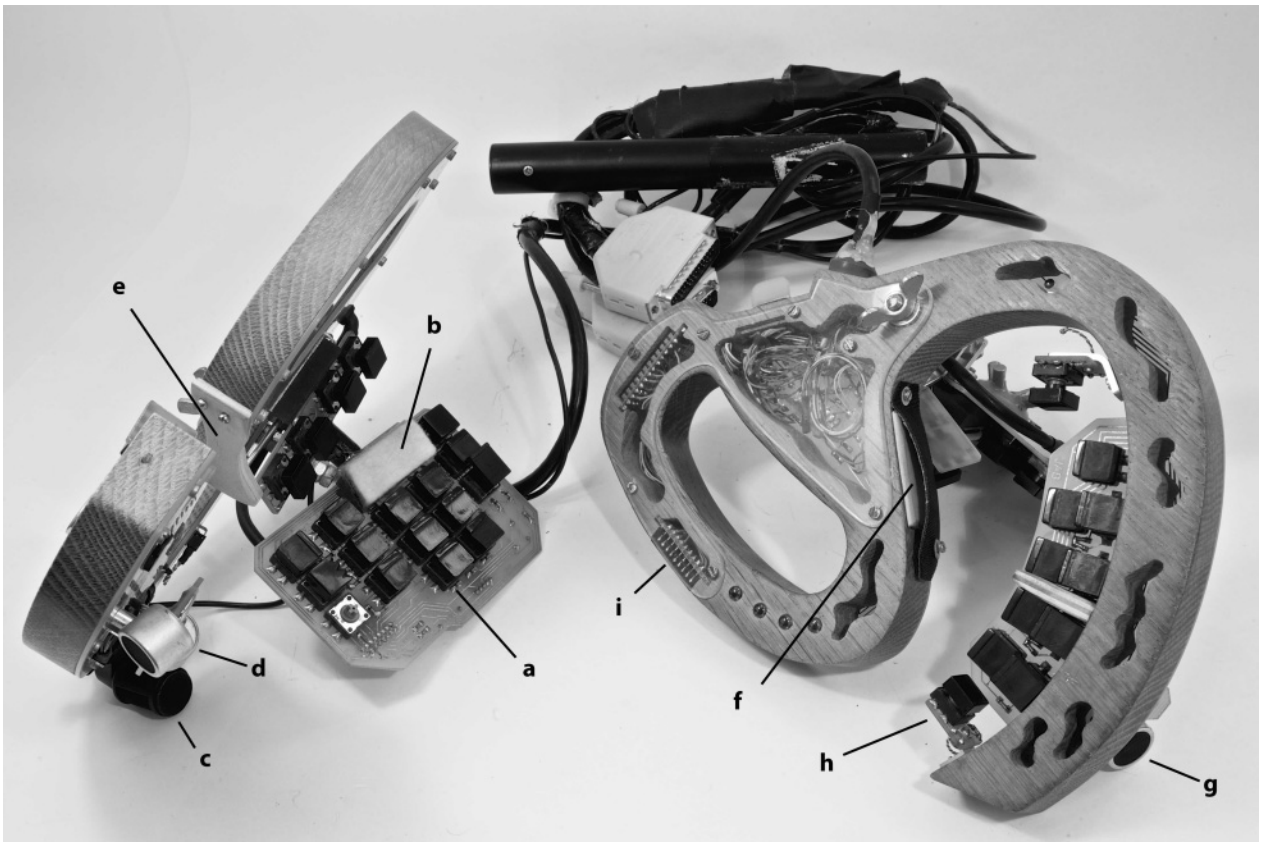


of The Hands, its sensor technology developed in order to be used by conservatory students—in other words, as an educational tool. The MIDI Conductor used the very first version of the SensorLab, a 19-inch-rack version that could only be programmed by its creator, Peter Cost. Six units were produced, and they were handed out to a duo (Frank Baldé and Michael Barker), to a trio (BMBCon, i.e., Justin Bennet, Roelf Toxopeus, and Wikke van't Hoof), and to Edwin van der Heide. More recently, Baldé modified his MIDI Conductor to be able to use it with the newer (and customizable) version of the SensorLab.

The Hands Version 2

The second version of The Hands was developed in 1990 (see Figure 2). The design was completely renovated and inspired by more ergonomic principles. Many more switches were added and the ones controlled by the thumbs were now placed perpendicularly to the keypads for the other fingers. This peculiar structure allowed for self support on the performer's hands without the aid of elastic bands. The left-hand data glove had 25 momentary push keys, 4 mercury switches, 2 pressure sensors, 3 UST-40R ultrasonic receivers, and a MKE 40-EW clip cardioid microphone connected to a powering module. The right-hand data glove had 25 momentary push keys, 4 mercury switches, 2 pressure sensors, a USR-40T ultrasonic transmitter, and a Siemens high-efficiency, red DLO2416 four-character display board that enabled the performer to see the currently activated function. In both data gloves, 16 of the 25 keys were placed in a 4×4 matrix configuration in order to be controlled by the index, middle, ring, and little fingers. A pressure sensor in each data glove

Figure 3. The Hands version 3. Left-hand data glove on the left; right-hand data glove on the right. Labeled components: pitch keys (a), pressure sensor (second pressure sensor in same location as f) in right hand (b), clip microphone (c), one of the three ultrasonic receivers (remaining two in same position as in The Hands *version 2) (d), potentiometer (e), ultrasonic transmitter (g), a close up of the thumb momentary switches (h), side of the four-character display board (i). (Photo courtesy of Daniel Buzzo.)*



was placed between the third and fourth row of keys. These pressure sensors were made from small portions of the aftertouch sensor bar from a Yamaha DX7. The remaining nine keys and the remaining pressure sensor on each data glove were controlled by the thumb.

The Hands Version 3

The third and last version of the Hands, which appeared in 2000, was designed by Waisvicz and built by Jorgen Brinkman (see Figure 3). The design is similar to version 2. This version provides even more switches. The left-hand data glove has 30 momentary push keys, 4 mercury switches, a pressure sensor, a potentiometer, 3 UST-40R ultrasonic receivers, and a MKE 40-EW clip cardioid microphone connected to a powering module. The right-hand data glove has 30 momentary push keys, 4 mercury switches, 2 pressure sensors, a USR-40T ultrasonic transmitter, and a four-character display board. On both data gloves, 19 of the 30 keys are controlled by the index, middle, ring, and little fingers. One of the pressure sensors in each data glove is placed between the third and fourth row of keys. The left-hand data glove has a potentiometer controllable by the thumb. The second potentiometer on the right-hand data glove is controlled by the thumb of the corresponding hand. The remaining eleven keys on both data gloves are also controlled by the thumb.

Complementary Software and Hardware

Each version of The Hands informed the development of software and hardware that complemented

the DMI system. Their development was guided by both the aesthetic goals of the performance and the technical needs for interfacing The Hands. The main tools that emerged from this research are the MIDI controller, the Lick Machine, the SensorLab and LiSa. All these tools, except for the MIDI controller that was uniquely built for The Hands, were subsequently further developed to be multipurpose devices, and they were officially released by STEIM.

The MIDI Controller

In version 1 of The Hands, the two data gloves connected via serial cable to a module attached to the performer's back: The Hands MIDI controller (at top of Figure 1). This module contained the entire circuitry. It was designed as a single-board microprocessor made of an eight-bit Rockwell 6511 microprocessor, three EPROMs containing the code for mapping the sensors's electrical signal to MIDI, a crystal for the system clock, a MIDI interface, and a power supply. One of the four available ports in the 6511 microprocessor was programmed as a serial port for the MIDI interface. In short, the module was an analog-to-MIDI converter. The program translating the sensors's electrical signal to MIDI messages was loaded via an EPROM programmer in one of the Apple IIe slots. The code was written in 6502 assembly language on an Apple IIe running the ProDOS operating system. After RAM initialization, the program ran as an endless loop that sequentially scanned for the key matrix, the mercury switches, the potentiometer, and the ultrasonic distance sensor. This data was then mapped to MIDI messages that would be sent to synthesizers and other MIDI devices via a MIDI splitter (seen at left in Figure 1).

The STEIM archives preserve five print-outs of five different versions of the assembly code used for version 1 of The Hands. All versions provide similar features, and their variations were implemented according to the needs of the specific performance in which they were used. Given these similarities, it is not possible to match with certainty a version of the assembly code to the performance in which it was adopted. The date reported on the header of each file provides, however, a plausible match for its use in a specific performance. It is important to note that all versions of the code seem to include the mapping for a reduced number of buttons compared with the number of physical switches that version 1 of The Hands appears to have today. It is plausible to think that the "extra buttons" were added at a later stage, immediately preceding the development of version 2 of The Hands.

Version 2.x of the assembly code was developed by Johan den Biggelaar and Wim Rijinsburger in 1985. Each switch and sensor was mapped to a different MIDI message. The twelve keys in each hand (pitch keys) triggered MIDI Note On and Note Off events within one octave. The four mercury switches were aligned to the four cardinal directions and tilted by about 30 degrees. This was done to allow either one or two switches to be "on" at the same time and thus allowing eight possible modes (ten, when including straight down and straight up) depending on the tilt of the hand. These eight modes activated eight different octaves, extending the range of the pitch keys to that of a piano. When the palm of the hand was horizontal and parallel to the ground, no switches were on. This was translated to no change, or octave 0. Given that a set of mercury switches was installed on each data glove, each hand could transpose to different octaves.

The distance between the two Hands was measured by the ultrasonic transmitter–receiver pair and mapped to note velocity. Thus, distance worked in The Hands as a continuous controller in which values between close and distant positions of The Hands were scaled to velocity values between 0 and 127. The four keys controlled by the thumb of the left hand are used to turn MIDI channels 1, 2, and 3 on and off (the fourth key switched all three channels simultaneously). The channel assignment applied to both Hands. The potentiometer, controlled by the right thumb, was used to control pitch bend. The four thumb keys on the right hand controlled toggles for sustain on/off, program change up, program change down, and the "scratch" function. The scratch function worked together with the ultrasonic distance sensor. When scratch is on, any variation in the distance between the two Hands produced a copy of the Note On event

currently active. Waisvisz considered the scratch function as probably the most important feature for The Hands, allowing him to "bow" the sound. Indeed, the speed with which the distance between the two Hands changed translated to a different rate of note repetition. The scratch function would be used to scratch samples in the later version of The Hands, when the speed of the software and hardware allowed for real-time manipulation of samples.

Version 3.4 of the assembly code was developed by Wim Rijinsburger and Paul Spaanderman in 1986. This version of the code was identical to the previous one except for the function assigned to the four thumb keys in the left hand. In this version, these keys worked as "modifier keys" in that their activation required an action by the right hand. The modifiers enabled four modes. Mode 0 enabled the normal Note On / Note Off mode for all pitch keys. Mode 1 enabled the "bank-select mode," which allowed the reserved two thumb keys on the right hand to browse through the program numbers. Mode 2 enabled the sending of each note event to channel 16. Mode 3 updated the MIDI channel to which each event triggered by both Hands would be sent. By selecting this mode all the twelve pitch keys of the right hand enabled the performer to select a different MIDI channel (up to a maximum of twelve channels).

Version 4 of the assembly code was developed by Wim Rijinsburger. This version was identical to version 3.4 except for different routines for modes 2 and 3. Mode 2 enabled the performer to select four different "pages." Page 1 diverted all MIDI notes and pitch bend data to channel 16. Page 2 allowed the performer to select a different MIDI channel. This feature was similar to mode 3 in version 3.4. In this version, however, each pitch key selected a different combination of channel selection between channels 1, 2, 3, and 16. Pages 2 and 3 as well as mode 3 did not present any mapping features.

Versions 5 (1986) and 6.10 (1988), developed by Wim Rijinsburger, presented identical mapping features to version 4, and they implemented only a more efficient routine for the ultrasonic sensor, written by Peter Cost. The code in version 6.10 presented right- and left-foot routines that did not execute any command. The data gloves, however, did not provide a foot sensor. Waisvisz had, in fact, thought to implement an extra foot sensor control, but he never fully pursued this function because it was eventually considered unneeded.

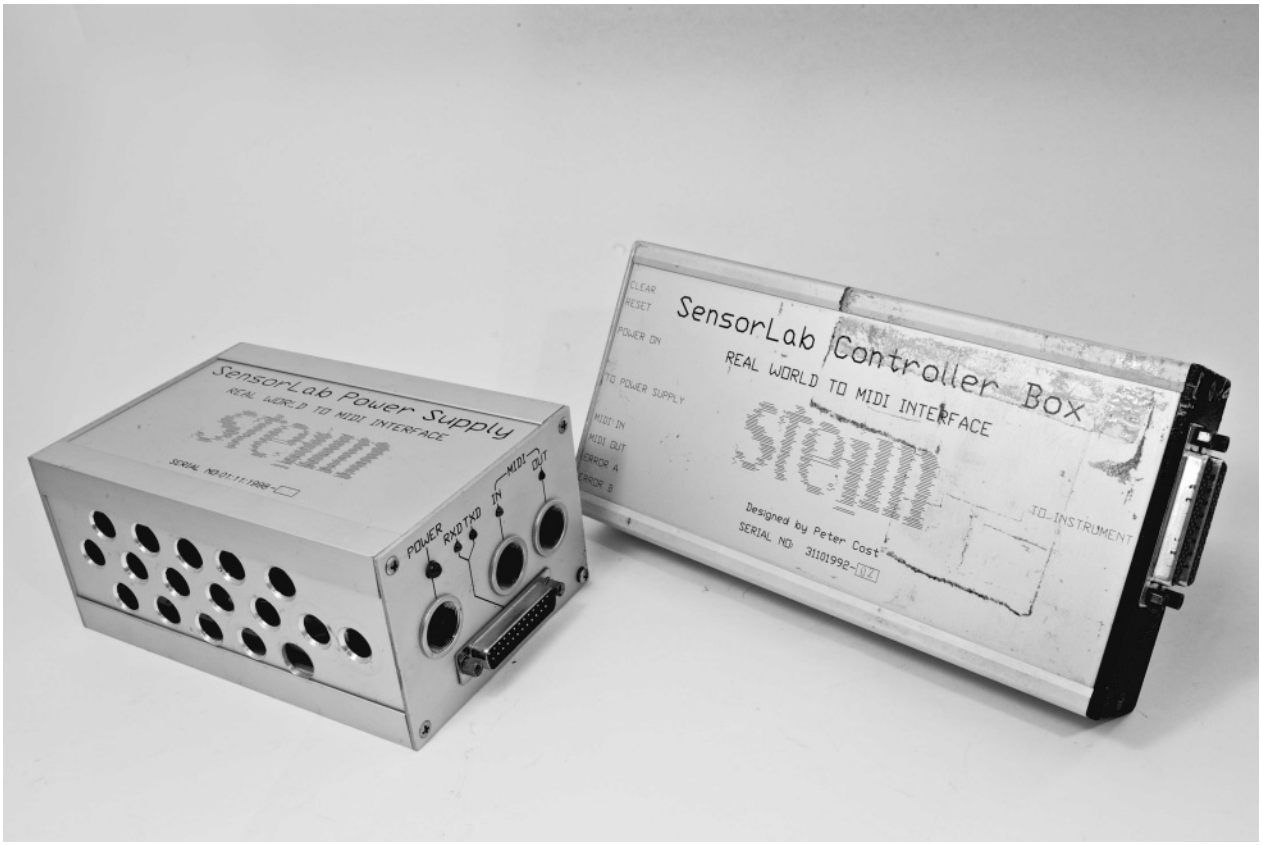
Lick Machine

The Lick Machine was developed at STEIM by Frank Baldé and Michel Waisvisz in 1989. The Lick Machine was software used with version 1 of The Hands and ran on the Atari 1040ST. It allowed the performer to trigger and modify multiple sequences of MIDI events (i.e., "licks") on the fly with a single MIDI message (e.g., a Note On message). With this software, the performer was able to control the tempo of the licks, their MIDI velocity, starting point, length, transposition, note density, and pitch deviation. The main aim of the software was to enable the performer to conduct a MIDI "orchestra." The Lick Machine was never ported to Mac OS X. An OS 9 version and its manual exist and are still available from the STEIM Web site for free (http://steim.org/product/discontinued-products).

SensorLab

As of version 2 of The Hands, the pair of gloves were interfaced with either a synthesizer or a computer via a dedicated analog-to-MIDI converter called SensorLab (see Figure 4). The development of the SensorLab started in 1989. A direct successor of the MIDI controller, its job was to convert the incoming analog signals from the available sensors to MIDI messages for interpretation by any MIDI equipment. Although developed as a general-purpose analog-to-MIDI converter, the analog readings were limited to sensors that closely matched the sensor technology used by The Hands: an 8×16-diode matrix key scanning 32 analog-to-digital channels with 7-bit resolution, and 2×3 ultrasonic distance sensors with 14-bit resolution. The analog-to-MIDI conversion was dealt with dynamically. A custom interpreter, named Spider, allowed for the programming of the SensorLab hardware according to the needs of the user. The Spider programming environment allowed the user to convert the analog signals to

Figure 4. STEIM SensorLab controller box and power supply with MIDI connections.



a desired MIDI message while also scaling and thresholding sensor data, as well as recalling preset configurations. These configurations were then uploaded to the SensorLab via a MIDI System Exclusive message.

Although a mandatory requirement for The Hands, STEIM stopped producing the SensorLab in 2004, owing to the high costs involved and the emergence of other, cheaper multipurpose analog-to-MIDI converters. A software version that greatly expanded on the dynamic approach to mappings used in the SensorLab was present in STEIM's Junxion software, released in 2003.

LiSa

In 1993, the development team working on The Hands decided to upgrade the Atari 1040ST to a Macintosh computer. This started an interest in research into audio sampling. It was decided to add extra digital signal processing (DSP) units to the Macintosh to allow for live sampling manipulation. The extra DSP was a Digidesign Nubus DSP card. Tom DeMeijer wrote the driver that connected the Apples's CPU to the extra DSP units. Frank Baldé developed software that supported the loading and live scratching of one sample (i.e., the scratch function in The Hands). The software did not support live recording of the sample, only playback. Still, the performer could control up to two pitches generated from the loaded sample. This software, called SAM, was adopted in some performances with version 2 of The Hands. In 1994, the team experimented with live recording of samples using a Peavey SX16 sampler. The Peavey sampler allowed the live recording of a sample of predetermined length via MIDI System Exclusive messages. Both

the SAM software and the Peavey sampler, however, proved to be quite unstable (i.e., they crashed often) and therefore were not suitable for live performance. It is important to note that this was not because of bad manufacturing, rather, that this application stretched the capacity of the technology.

These considerations led the team to consider the possibility of writing custom software that enabled the live sampling functionality they were looking for. In 1995, after one year of development by Frank Baldé, LiSa (Live Sampling) was ready, and it was publicly released in 1997. LiSa enabled the recording and manipulation of multiple samples on the fly and was initially developed for Macintosh OS 9. The fast-changing scenarios produced in the computer industry required many changes to the software in the years to come. LiSa X was the version compiled for Mac OS X. LiSa XC was a player introduced with the adoption of Intel-based processors by Apple. LiSa XC allowed for the loading of patches made in LiSa X to allow them to run on an Intel-based computer. LiSa XC remained Waisvisz' software of choice for The Hands. The development and release of the STEIM's general-purpose software (never used by Waisvisz), called RoSa (Real-time OSC-controlled Sampler), in 2013 draws greatly on the experience gained by the design of LiSa.

Performance Setups for The Hands

We now take a look at the performance setups used with The Hands. There were significant changes in the setups used between the first two versions of The Hands, but from version 2 onwards the performance setup remained relatively stable. For this reason we will discuss the setup for versions 2 and 3 together.

Performance Setups in Version 1

Waisvisz publicly presented and performed with The Hands for the first time in June 1984 at the Amsterdam Concertgebouw on the occasion of the premiere of his composition *Beat Concert*. Waisvisz declared that this initial experience with The Hands informed much of the development of the later versions of the software (Waisvisz 1985a). From the assembly code available (presumably version 2.x) and his paper presented at the International Computer Music Conference, it seems that this early prototype of The Hands controlled up to three different voices (via three separate MIDI channels) on a single Yamaha DX7 synthesizer. The STEIM archive contains recordings of two works that were performed with version 1 of The Hands: *Touch Monkeys* and *Archaic Symphony*.

Touch Monkeys was premiered on 13 October 1986 at the Pompidou Center in Paris. It was commissioned by IRCAM and the Centre Pompidou, with a supporting grant from the Dutch Fund for the Creative Arts (Dutch Ministry for Culture). The audio recording of the premiere can be found in IRCAM's audio/video archive. A video recording of the performance is also available on the STEIM archive, and it is a recording of Waisvisz performing at the First International Art Rock Festival in Frankfurt, Germany, in 1987.

In *Touch Monkeys*, The Hands controls 18 digital instruments. Twelve are controlled directly by The Hands, which performs timbral transformations on these instruments. The twelve instruments are created on a Yamaha TX-816 MIDI Rack, which holds up to eight individual TF1 modules. Each TF1 module is a copy of the DX7 monophonic synthesizer. Polyphony was achieved by routing each pair of synthesizers to channels 1 to 6 (two synthesizers listening to the same channel). The remaining six instruments are created on an Atari 1040 ST. Each instrument on the Atari holds a music sequence. The Hands can select which sequence to play and can modify this sequence's notes in real time. Each of the Atari's six instruments is then spatialized on six different speakers via a mixer with six direct inputs and six direct outputs.

A second work for The Hands version 1 is *Archaic Symphony*. This work was commissioned by the San Francisco Symphony and premiered in San Francisco on 12 December 1987. The development of this performance was sponsored by a grant from the Dutch Fund for the Creative Arts (Dutch Ministry for Culture) with support from the Royal Conservatoire in The Hague, STEIM, the municipalities of The Hague and Amsterdam, Ampco Flashlight Rental, Groupe

de musique électroacoustique de Bourges (GMEB), Synton, E-MU Systems, and Yamaha. Between 1987 and 1991, Waisvisz performed *Archaic Symphony* in several other international venues and festivals, such as the Royal Conservatoire in The Hague, Festival internationale de musique expérimentale (Bourges), the Berlin Philharmonic, the Almeida Festival (London), the International Computer Music Conference in Cologne, and the Auditorium de la maison of Radio France. The STEIM archive preserves a video recording of the performance held in 1988 at the Frascati Theatre, Amsterdam.

Similarly to *Touch Monkeys*, in *Archaic Symphony* the performer is able to control both individual sounds and prerecorded sequences of MIDI events. The Hands's MIDI controller sends messages to an Atari 1040ST. The MIDI out port of the Atari then connects to the MIDI in of a Yamaha MEP4 MIDI interface. The MIDI thru port of the MEP4 is used to connect to a DX7 synthesizer for the direct manipulation of sounds by the performer. The MEP4's four MIDI out ports are connected to three synthesizers (TX7, TX802, EMax) that play stored sequences of MIDI events received from the Lick Machine. Thus, the Lick Machine allows the performer to conduct an orchestra. The number of instruments forming this virtual orchestra varied from performance to performance. For the premiere in San Francisco, Waisvisz controlled up to 58 instruments. In what Waisvisz considered the "final version" of *Archaic Symphony*, a 1988 performance in Amsterdam, the number of instruments controlled was 35.

Performance Setups in Versions 2 and 3

With the introduction of the second version of The Hands, the performance setup became somewhat more standardized. The two data gloves connected to the SensorLab, which provided an interface to a Power Macintosh running LiSa. A Yamaha VL70 physical-modelling synthesizer was only occasionally used with version 2 of The Hands. It is clear, however, that the availability of faster CPUs allowed Waisvisz to rely more and more on samples rather than pure synthesizer sounds. The LiSa software played an important role in this regard, since it allowed Waisvisz to think of The Hands as a modular system. Indeed, whereas the MIDI parameters of The Hands remained almost identical (aside from minor changes in the Spider code for the SensorLab), each LiSa patch could be easily tailored to the needs of a specific performance. The STEIM archives preserve the last LiSa patch developed by Waisvisz for version 3 of The Hands, named "Thisisit." The Hands controlled six portions of a loaded sample in LiSa via six MIDI channels enabled by the thumb keys. A seventh MIDI channel was reserved for the start and stop controls of a Peavey sampler (used with The Hands version 2). An eighth MIDI channel was reserved for the loading of an extra sample. Finally, a ninth channel was reserved for communication with a VL70 synthesizer (used with The Hands version 3). The pitch keys pitch-shifted the currently selected sample across the eight octaves determined by the position of the mercury switches. The pressure sensor provided a glissando effect. Several modes, as in version 1 of the Hands, were enabled via the thumb keys and provided different functions for the distance sensor data. The ultrasound sensor data could work as a movable playback head within the selected buffer (i.e., a scratch function), as a selector for the length of the sample (stretching or shrinking), or as a controller for Note On velocity. Another mode offered the ability to use the pitch keys as a pattern selector. The patterns are rhythmic sequences stored in the LiSa patch by taking small snippets of sounds in the loaded buffer. Other thumb keys allowed Waisvisz to browse and recall a sample within his samples library. Another key, activated under the appropriate mode, enabling the playing of the selected sample backwards.

The available mappings required an impressive motor memory from the performer. For the system to work, performers are required to know exactly where they are in each selection routine and where the sound manipulation was left in each channel to organically continue in the dialogic process initiated for each sample. Furthermore, to browse the samples library, it is necessary to have an accurate knowledge of its hierarchical structure. Still, it is important to note that not all the keys in The Hands were in

use. In fact, there were many inactive keys that had been implemented at the design phase as "spare" sensors in case of future needs. These needs never manifested, however, given the already intricate mappings.

In addition to this, The Hands recorded and manipulated samples in real time via the clip microphone. The performance held in 1997 at the Zeebelt Theatre in The Hague is emblematic for the extent of this feature's use. Presented to one spectator at a time, the performance was built entirely on live recordings of the spectator's voice and sounds, which were subsequently morphed and harmonized in real time via LiSa. In later performances, Waisivisz would adopt this live-sampling technique sparsely and in support of a more robust structure built upon a well-defined set of prerecorded samples. In fact, it was from years of long work, crafting a personal samples library, that a symbiotic relationship between the hardware (The Hands and SensorLab) and the software (LiSa) eventually developed. This made The Hands a unique instrument, allowing Waisvisz to become a virtuoso of his own DMI. Neither patching nor further software or hardware development was required in the later years. The LiSa XC player, minimal in its duties in that it loaded patches only and provided little to no visual feedback, was sufficient and perfectly suited to Waisvisz's needs and let him focus entirely on the navigation and performance of his own sonic space.

Conclusion

The time invested in the development of The Hands allowed for the crafting of an instrument that, in its last version, appears as a fully finished product with researched design and comfort in wearability. The one feature not implemented, that would almost immediately strike the attention of a modern reader, is the lack of a wireless communication with the host computer. In fact, from its first to final versions, The Hands is a wired instrument. Sometimes cables ran for several meters to accommodate the performer's need to move freely on stage. This was an informed choice, surely not dictated by the technological challenges presented by wireless technology in the early 2000s. The dominant reason lies most likely in that, from time to time, Waisvisz used to interface The Hands with his old synthesizers, which he appreciated for the quality of sounds. Furthermore, all technical developments stopped with version 3 of The Hands. Waisvisz was satisfied with the technology in use. He was now mastering his DMI in its finest details from the hardware to the software.

Several technical constraints played a major role for the development of The Hands. These depended largely on the technology available at the time. There is a difference, however, on how these constraints presented themselves throughout the various versions of The Hands. Indeed, many of the constraints informing the development of the first version of The Hands were dictated by the hardware resources of the available technology of the time. This technology included synthesizers and computers of extremely limited CPU capacity (e.g., Atari). From a developmental point of view, the goal was to make as much as possible out of what was available. With later versions of The Hands, the constraints become less and less dictated by the available technology. In fact, computational power begins to reach, and even exceed, realistic needs. In doing so, the constraints informing the research on The Hands, imposed by the technological industry of the 1980s, gradually became self-imposed as we get closer to the last version of this DMI. There is a shift in the approach of the setup that goes from maximizing to minimizing. A testament to this is provided by comparing the intricate setup of the early performances (e.g., *Touch Monkeys* and *Archaic Symphony*) and the "bare" technology involved in his late performances (The Hands, LiSa XC, and no prerecorded samples).

This approach to minimizing the setup extends also to the selection of the sonic material used in a live performance. In fact, from *Archaic Symphony*, in which he controlled up to a total of more than 60 instruments, Waisvisz gradually reduced his sound palette to nothing but the indeterminacy of the sonic environment of the live venue. Then he eventually settled on an intermediate position which sees him manipulating a carefully

Figure 5. Michel Waisvisz performing with The Hands (unknown date and location).

crafted, personal sample library by means of spectral transformations, scratching, overlapping, transpositions, and reverberation. All this helped create a sonic environment that evolved towards depth and complexity.

In light of these considerations, it is probably with the last version of The Hands that we can more confidently describe this DMI as an instrument rather than a controller—a difference in terminology that Waisvisz was aware of since his earliest performances (Waisvisz 1985b). Should DMIs enable the performer to directly manipulate the finest details of the sound-producing mechanisms (as in traditional instruments) or control a series of events (i.e., a controller)? The theme of *Touch Monkeys*, for example, deals exactly with this issue, anticipating a debate that was to engage specialized audiences for decades to come. It is indeed with *Touch Monkeys* that Waisvisz presents this debate by contrasting two opposite characters enacted by the two methods of manipulation of sound. On the one hand, the performer produces and manipulates sounds directly by interfacing with the oscillators of a synthesizers. On the other hand, the performer recalls and manipulates sequences of events (e.g., MIDI notes) that are stored in a computer (i.e., Atari 1040ST and the Lick Machine). To some extent, the raison d'être of the "controller versus instrument" debate lies in the technical details of The Hands, which enabled a combination of switches and continuos controllers. These are indeed often associated with the making of a controller or an instrument, respectively. Still, The Hands informs us that it may be time and practice that make a DMI an instrument. In fact, if in its earliest versions The Hands is correctly described as a controller, time and practice let it slowly become an instrument. In contrast with an approach to the design of instruments that always starts from scratch, The Hands remained substantially the same instrument in all three versions (Dykstra-Erickson and Arnowitz 2005). This allowed Waisvisz, over time, to master his own DMI more and more. With the last version of The Hands, the distinctions between hardware and software, and between switches and continuous controllers, seem to disappear. Waisvisz has become a virtuoso, a "composer of timbres" (Krefeld and Waisvisz 1990), who let the whole "merge" into one unique instrument: The Hands (see Figure 5). His perseverance in refining the details of a single instrument throughout the years allowed The Hands to become a milestone in the DMI literature.

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