MAD-X: AN INSTRUMENT WITHOUT A FIXED VOICE

ALI BALIGHI

Abstract (IT): *MAD-X* è uno strumento musicale digitale a otto canali basato su sensori di prossimità, che mette in discussione l'assunto secondo cui uno strumento musicale mantenga una relazione stabile tra forma fisica, tecnica esecutiva e identità sonora. Le concezioni convenzionali degli strumenti presuppongono una corrispondenza fissa tra costruzione, gesto e suono; gli strumenti elettronici e informatici interrompono questa corrispondenza separando l'interfaccia di controllo dal processo di produzione del suono, rendendo necessario progettare esplicitamente la loro relazione attraverso il mapping. L'articolo affronta questo problema attraverso la progettazione e la valutazione di MAD-X, il cui involucro personalizzato ospita otto sensori di prossimità VCNL4030 che trasmettono dati MIDI ad ambienti SuperCollider intercambiabili. Il metodo combina la documentazione tecnica dell'architettura di sensing, mapping e sintesi dello strumento con un'osservazione strutturata, condotta dal progettista-esecutore, della tecnica gestuale in quattro configurazioni sonore contrastanti. Il risultato principale è che il vocabolario gestuale dello strumento — avvicinarsi, allontanarsi, sostare, muoversi lateralmente — rimane stabile tra le configurazioni, mentre le sue conseguenze musicali, tra cui accordatura, articolazione, timbro e comportamento spaziale, cambiano sostanzialmente. L'articolo sostiene che questa stabilità del gesto unita alla mutabilità dell'esito musicale costituisce un'inversione della relazione convenzionale mezzi-fini tra strumento e musica, collocando MAD-X come un'infrazione paradigmatica che ridefinisce lo strumento come evento prodotto attraverso configurazione, interazione e ascolto, piuttosto che come veicolo fisso per risultati musicali predeterminati.
Parole chiave: liuteria digitale; identità strumentale; mapping gesto-suono; infrazione paradigmatica; sensing di prossimità.

Abstract (EN): *MAD-X* is an eight-channel, proximity-based digital musical instrument that questions the assumption that a musical instrument maintains a stable relationship among physical form, performance technique, and sonic identity. Conventional accounts of instruments presuppose a fixed correspondence between construction, gesture, and sound; electronic and computer-based instruments disrupt this correspondence by separating the control interface from the sound-producing process, requiring their relationship to be explicitly designed through mapping. This article addresses that problem through the design and evaluation of MAD-X, whose custom enclosure houses eight VCNL4030 proximity sensors transmitting MIDI data to interchangeable SuperCollider environments. The method combines technical documentation of the instrument's sensing, mapping, and synthesis architecture with structured designer-performer observation of gestural technique across four contrasting sound designs. The principal finding is that the instrument's gestural vocabulary — approaching, withdrawing, hovering, and lateral movement — remains stable across configurations, while its musical consequences, including tuning, articulation, timbre, and spatial behavior, change substantially. The article argues that this stability of gesture combined with the mutability of musical outcome constitutes an inversion of the conventional means–ends relationship between instrument and music, positioning MAD-X as a paradigmatic infraction that reframes the instrument as an event produced through configuration, interaction, and listening, rather than a fixed vehicle for predetermined musical results.
Keywords: digital lutherie; instrumental identity; gesture-to-sound mapping; paradigmatic infraction; proximity sensing.

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Introduction

A musical instrument is commonly understood through a comparatively stable relation among its material construction, the actions required to play it, and the sounds those actions produce. In many acoustic instruments, the playing interface and the sound-producing body are physically coupled, so the performer's gesture acts upon the same material system that generates the audible result[1]. Electronic and computer-based instruments reorganize this relation because the control interface and the sound source may be separated, requiring their connection to be explicitly designed through mapping[2]. Different mapping strategies can alter the character and playability of an electronic instrument even when its controller and synthesis process remain unchanged[3].

MAD-X examines this separation through an eight-channel, proximity-based digital musical instrument housed in a custom enclosure designed in Autodesk Fusion 360. The completed instrument uses eight Adafruit VCNL4030 proximity sensors arranged as two groups of four. Their readings are acquired through an eight-channel I²C

[1] Andy HUNT, Marcelo M. WANDERLEY, Matthew PARADIS, *The Importance of Parameter Mapping in Electronic Instrument Design*, in «Journal of New Music Research», vol. 32, no. 4, 2003, p. 429.

[2] *Ibidem.*

[3] Andy HUNT, Marcelo M. WANDERLEY, *Mapping Performer Parameters To Synthesis Engines*, in «Organised Sound», vol. 7, no. 2, 2002, p. 100.

multiplexer by an Adafruit Feather RP2350 microcontroller, converted into MIDI control-change messages, and transmitted by USB to SuperCollider. SuperCollider defines the instrument's tuning, gesture-to-sound mappings, synthesis processes, articulation, timbral transformation, and spatial behavior. The physical device therefore remains recognizable across performances, while the computational organization through which it becomes musically operative can be replaced.

This reconfigurability is not treated here as a secondary convenience. Digital instruments can change mappings and synthesis behavior through code, allowing a stable physical interface to support multiple modes of operation[4]. In MAD-X, loading a different SuperCollider environment may alter the division of the octave, the conversion of proximity values into pitch positions, the way sound is excited, and the functions assigned to individual sensors. Each configuration therefore establishes a particular relationship among bodily distance, numerical control, tuning, articulation, timbre, and space.

The central thesis of this article is that MAD-X is a physically stable but sonically mutable digital instrument whose identity emerges from the changing relationships among proximity sensing, bodily gesture, control mapping, tuning structure, and SuperCollider synthesis. The phrase "without a fixed voice" does not imply an absence of identity. It identifies voice as a configurable organization of tuning, timbre, articulation, temporal response, spatial behavior, and gestural control. Software-based musical practice can weaken conventional distinctions among instrument,

[4] John SULLIVAN, Marcelo M. WANDERLEY, Catherine GUASTAVINO, *From Fiction to Function: Imagining New Instruments through Design Workshops*, in «Computer Music Journal», vol. 46, 2022, pp. 39-40.

composition, and performer because software may function simultaneously as a tool, a composed structure, and a medium of performance[5].

Two research questions guide the discussion. First, how does MAD-X complicate the idea that a musical instrument possesses a stable relationship among physical form, performance technique, and sonic identity? Second, how does the translation of continuous proximity gestures into discrete pitch structures and continuous sonic transformations shape the instrument's performance practice? The article first develops the concept of an instrument without a fixed voice, then documents the design, physical architecture, sensing, mapping, and synthesis systems. It subsequently examines performance practice, technical and practice-based observations, the instrument's relation to the call's notion of paradigmatic infraction, and the present limitations of the project.

1 - The Instrument without a Fixed Voice

1.1 - Fixed body, mutable voice

As established above, this mutability does not imply an absence of identity. The enclosure and sensor layout remain materially recognizable, but the computational relations attached to them can be revised. The same hand movement can therefore acquire a different musical function when another SuperCollider configuration is loaded.

[5] Oliver BOWN, Alice ELDRIDGE, Jon MCCORMACK, *Understanding Interaction in Contemporary Digital Music: From Instruments To Behavioural Objects*, in «Organised Sound», vol. 14, no. 2, 2009, pp. 188-191.

This mutability follows from the separation of control interface, mapping layer, and sound generator in digital instrument design. Mapping is not a neutral transmission stage; it is the designed relationship through which performer actions become synthesis parameters[6]. Altering that relationship can change the character of an electronic instrument even when its physical interface and sound source remain constant[7]. Multilayer mapping structures can also retain one controller while substituting another synthesis method, allowing physical continuity without requiring sonic continuity[8].

Layer	**Status in MAD-X**
Enclosure and sensor positions	Relatively stable
Sensor calibration	Adjustable
MIDI assignments	Reconfigurable through firmware
Gesture–sound mappings	Reconfigurable
Tuning structure	Reconfigurable
Synthesis and processing	Reconfigurable
Sonic identity	Emergent and mutable

[Tab 1. - Layers constituting the MAD-X system and their relative degree of stability, from the physically fixed enclosure and sensor positions to the fully reconfigurable synthesis and processing layer in SuperCollider]

[6] Andy HUNT, Marcelo M. WANDERLEY, *Mapping Performer Parameters To Synthesis Engines* cit., pp. 97-98.

[7] Andy HUNT, Marcelo M. WANDERLEY, Matthew PARADIS, *The Importance of Parameter Mapping in Electronic Instrument Design* cit., p. 429.

[8] *Ivi*, pp. 437-438.

These layers are not equally fluid. "Mutable" therefore describes a designed range of reconfiguration, not the absence of constraints. Digital instrument design remains conditioned by hardware, protocols, programming environments, aesthetic decisions, and the performer's accumulated technique[9].

1.2 Instrumental identity as a configuration

MAD-X becomes musically operative through the alignment of several elements: physical enclosure + sensing field + firmware + MIDI mapping + SuperCollider program + performer action

No single term in this sequence is sufficient to define the instrument. The enclosure establishes the spatial arrangement of the eight sensing zones, but it does not determine what those zones will sound like. The sensors produce numerical readings, but those values acquire musical significance only through calibration, transmission, mapping, and synthesis. SuperCollider supplies tuning and sound behavior, but the program does not constitute MAD-X independently of the physical sensing geometry and the gestures through which it is performed.

This account corresponds to scholarship that treats the digital instrument as structurally divided between interface and sound engine, with mapping defining the constraints through which the two operate as a musical system[10]. The symbolic organization of a digital instrument is designed rather than produced solely by the physical behavior of vibrating material; its computational structure therefore

[9] Thor MAGNUSSON, *Designing Constraints: Composing and Performing with Digital Musical Systems*, in «Computer Music Journal», vol. 34, no. 4, 2010, pp. 64-65.

[10] *Ibidem.*

participates in defining what actions become musically meaningful[11]. The programming environment is also not an empty container, because its abstractions and idiomatic procedures can influence instrument design, composition, and performance[12].

The physical object nonetheless remains consequential. A digital instrument's identity can arise from the combination of an embodied interface, control inputs, mappings, synthesis, and a developing gestural vocabulary rather than from any component in isolation[13].

1.3 Embodiment, digital lutherie, and configuration

Repeated performance converts a technical configuration into an embodied practice. Enactive approaches to instrument design describe action and perception as mutually dependent: performers act in response to what they perceive, while repeated interaction produces tacit knowledge of the instrument's behavior[14]. A change of software configuration can disturb this learned relationship even when the enclosure remains unchanged.

[11] Thor MAGNUSSON, *Of Epistemic Tools: Musical Instruments As Cognitive Extensions*, in «Organised Sound», vol. 14, no. 2, 2009, pp. 168–169.

[12] Andrew MCPHERSON, Koray TAHIROĞLU, *Idiomatic Patterns and Aesthetic Influence in Computer Music Languages*, in «Organised Sound», vol. 25, no. 1, 2020, pp. 53–54, 58–61.

[13] Dan OVERHOLT, *The Musical Interface Technology Design Space*, in «Organised Sound», vol. 14, no. 2, pp. 217–219.

[14] Georg ESSL, Sile O'MODHRAIN, *An Enactive Approach To The Design Of New Tangible Musical Instruments*, in «Organised Sound», vol. 11, no. 3, 2006, p. 287.

Digital lutherie further complicates fixed instrumental identity because designing, building, mapping, composing, and performing may belong to the same practice[15]. Interactive systems can likewise blur distinctions among instrument, composition, system design, and performance while retaining a recognizable identity across varying realizations[16]. Performance-ecosystem accounts extend this position by locating musical behavior in relations among performer, instrument, computational processes, composition, and environment[17].

MAD-X is therefore treated here as a configurable instrument rather than either a self-contained object or a generic controller. In this article, voice refers not only to timbre but to the combined organization of tuning, articulation, temporal response, spatial behavior, and gestural control.

2 - Design Aims and Development Process

MAD-X was developed around two related aims. The first was to create a non-contact performance interface in which hand distance, rather than mechanical pressure or surface contact, functions as the principal input. Sliders, buttons, and touch-sensitive controls would have required the performer to locate, touch, and manipulate several separate objects, often through relatively deliberate movements. In my performance practice, I wanted an interface that could respond to faster changes of position and

[15] Nathan RENNEY, Benedict GASTER, *Insights Into How Digital Luthiers Approach Design*, Proceedings of the International Conference on New Interfaces for Musical Expression, 2024, pp. 1-2.
[16] Jon DRUMMOND, *Understanding Interactive Systems*, in «Organised Sound», vol. 14, no. 2, p. 124.
[17] Arne EIGENFELDT, *Real-time Composition as Performance Ecosystem*, in «Organised Sound», vol. 16, 2011, no. 2, pp. 145-146.

support a performance situation oriented toward immediate sonic experimentation. This was a design objective derived from my own compositional needs, not a claim that non-contact sensing is inherently faster or more expressive than contact-based control.

The second aim was to prevent the physical instrument from becoming tied to one synthesis method, tuning system, or timbral model. I wanted the enclosure and sensor arrangement to remain recognizable while allowing the instrument's musical behavior to be rewritten in SuperCollider. The design process therefore treated sensing, mapping, sound generation, and performance as connected parts of the same practice. This integration corresponds with accounts of digital lutherie in which the roles of designer, builder, and performer frequently overlap[18].

Eight VCNL4030 proximity sensors were selected to create eight independent sensing regions. Their number and arrangement were modeled loosely on two-handed computer-keyboard technique. Four fingers from each hand are assigned to a separate group, while the thumbs are excluded because MAD-X does not require an equivalent to the keyboard's larger space bar. The precise assignments remain dependent on the active SuperCollider configuration.

The sensor array is accessed through an Adafruit eight-channel I²C multiplexer and managed by an Adafruit Feather RP2350 microcontroller. These components were selected because they were affordable, available, and comparatively straightforward to integrate within the intended system. USB MIDI was chosen as the communication layer because it provided a familiar connection between the completed hardware and the computer. SuperCollider was selected because it is the open-source environment I regularly use for composition and because it allowed tuning, mapping, synthesis, processing, and spatial behavior to be revised within the same programming system.

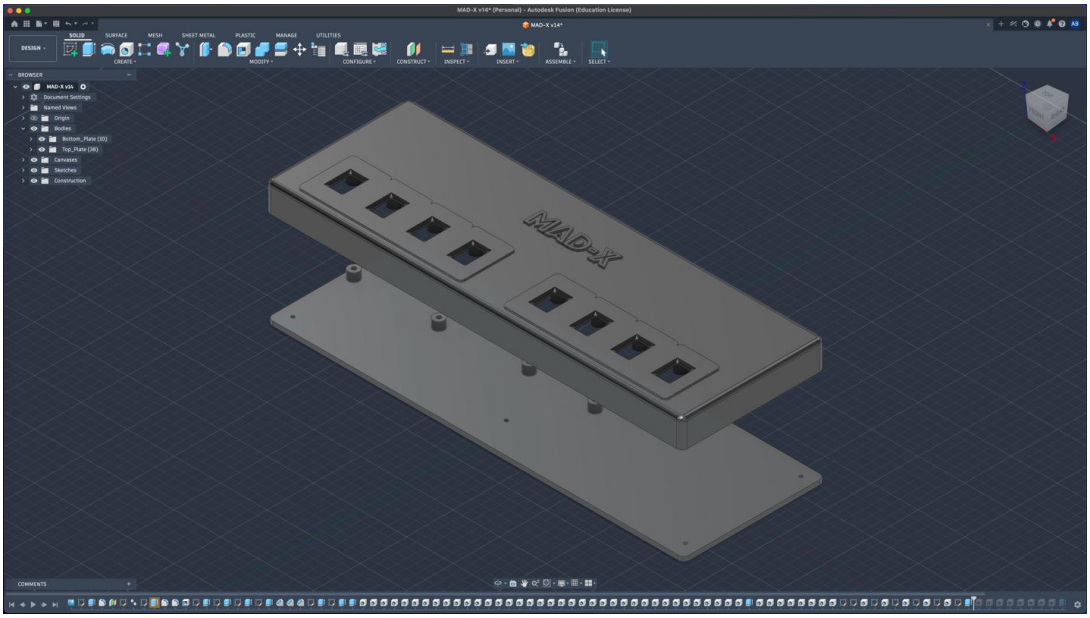
[18] Nathan RENNEY, Benedict GASTER, *Insights Into How Digital Luthiers Approach Design* cit., p. 1.

I designed the enclosure in Fusion 360, integrated the electronics, wrote the firmware, developed the SuperCollider environments, and tested the completed instrument through performance. The most consequential conceptual revision was a shift away from an initially percussion-oriented design. Restricting MAD-X to percussion sounds would have narrowed the role of the sensor array. Reframing it as an experimental instrument allowed the same hardware to support contrasting tunings, synthesis processes, mappings, and performance behaviors.

3 - Physical and Electronic Architecture

3.1 - Enclosure and sensor geometry

MAD-X is housed in a custom enclosure designed in Autodesk Fusion 360 (FIGURE 1) and fabricated as two separate components. The top and bottom parts have individual CAD bounding dimensions of 224 × 77 × 16 mm and 224 × 76 × 7 mm, respectively. Because the two components overlap when assembled, the completed enclosure measures 224 × 77 × 18 mm. The enclosure walls are 2 mm thick. The top and bottom sections are joined with M2 screws through the internal connection points.

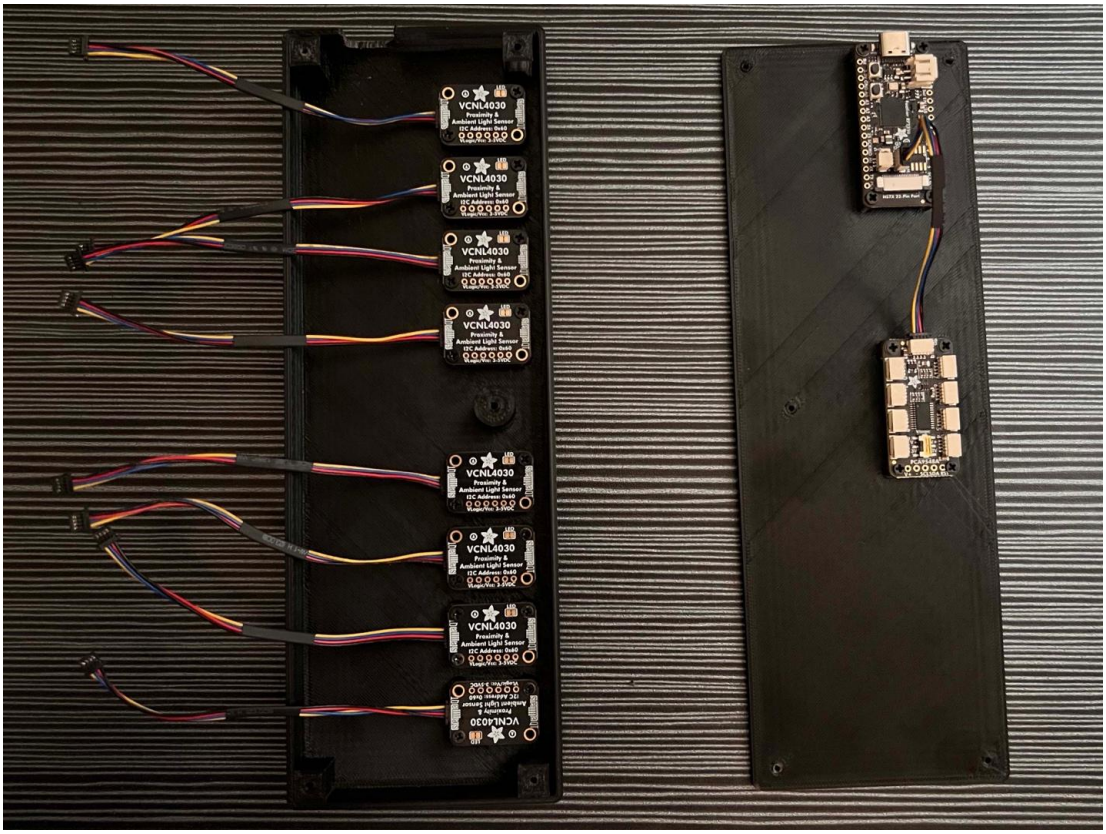


[**Fig. 1.** - The 3D model of MAD-X in Autodesk Fusion 360]

The enclosure is not treated merely as protection for the electronics. Its geometry defines the locations in which performance gestures occur. Eight sensor boards are mounted to the underside of the top component, while their sensing regions remain exposed through openings in the upper surface. Each board is secured with screws. The CAD model provides a rectangular optical opening of approximately 10 × 14.2 mm for each sensor, positioned within a wider tapered recess. This recessed form exposes the active region while reducing the degree to which the complete sensor board projects above the enclosure surface.

All eight sensing zones are arranged in a single horizontal row. Within each four-sensor group, adjacent sensor centers are separated by approximately 22 mm. The distance between the centers of Sensors 3 and 4 is approximately 44 mm. The larger central gap distinguishes the two groups spatially and reflects their different general musical functions.

The Adafruit Feather RP2350 microcontroller and Adafruit PCA9548A multiplexer are mounted to the bottom component with screws. Internal standoffs between approximately 5 and 7 mm support the electronic boards above the enclosure floor. The connection structure between the top and bottom components uses 15 mm mounting elements and M2 hardware. The USB-C connector is the only external connection, and its access opening is positioned on the left side of the enclosure.



[**Fig. 2. -** Open MAD-X enclosure showing the internal electronic layout, with the Adafruit Feather RP2350 microcontroller and PCA9548A multiplexer mounted to the bottom component and the eight VCNL4030 sensor boards secured to the underside of the top component]

3.2 - Instrument layout

Sensors 0 through 7 transmit MIDI control-change numbers 20 through 27, with Sensors 0–3 generally functioning as pitch selection or excitation and Sensors 4–7 as sonic, spatial, or timbral transformation. These roles describe the current organizational tendency of MAD-X rather than permanent functions; the active SuperCollider configuration determines the exact behavior assigned to each control stream.

4. Sensing, Mapping, and Synthesis Architecture

4.1 - Sensor Acquisition, Calibration, and MIDI Transmission

The complete signal path is:
hand movement → VCNL4030 sensors → PCA9548A multiplexer → RP2350 microcontroller → USB MIDI → SuperCollider → audio output.
The Feather RP2350 firmware reads the eight sensors sequentially: it selects one multiplexer channel, requests the corresponding proximity value, converts it into a MIDI-compatible range, and proceeds to the next sensor. Although the installed multiplexer is a PCA9548A, the firmware accesses it through the compatible adafruit_tca9548a library.
The current calibration sets a raw-data range of PROX_MIN = 150 and PROX_MAX = 4000, specific to the assembled enclosure: the lower bound is the approximate baseline at roughly 30 cm, while the upper bound is a reading taken closer than about 5 mm to the case. Each raw reading is constrained before transmission (clamped_prox = max(PROX_MIN, min(PROX_MAX, prox))), so movement outside this range produces no additional control variation. Values within range are mapped linearly to

a seven-bit MIDI interval (val = int(((clamped_prox − PROX_MIN) / (PROX_MAX − PROX_MIN)) × 127)). SuperCollider applies an additional lower gate, replacing values from 0 through 6 with zero to suppress low-level activity.

As noted above, Sensors 0–7 transmit as CC20–27. After calculating a sensor's new value, the firmware compares it with the previously transmitted value and sends a message only if it has changed (if val != prev_values[i]: midi.send(ControlChange(CC_CHANNELS[i], val))). This reduces redundant transmission but does not create a deadband: a single-unit fluctuation can still generate a new message. SuperCollider moderates the audible effect of small, rapid variations through Ramp and Lag3 smoothing, using longer periods for Sensors 4–7 (continuous transformations) and shorter periods for Sensors 0–3 (event-oriented functions).

After all, eight channels are examined, the firmware pauses for 5 ms — only a programmed delay between scan loops, not the instrument's full response time, which also depends on sensor conversion, sequential multiplexer access, the software-based I²C bus (50 kHz), MIDI transmission, SuperCollider processing, and audio buffering.

4.2 - Continuous gesture and discrete pitch

The central mapping process in MAD-X can be represented as:

continuous spatial movement → continuous sensor data → MIDI control values → discrete pitch position and/or continuous sonic transformation

This process demonstrates that mapping functions as an active design layer rather than as a transparent connection between interface and synthesis[19]. On the pitch-oriented

[19] Andy HUNT, Marcelo M. WANDERLEY, Matthew PARADIS, *The Importance of Parameter Mapping in Electronic Instrument Design* cit., p. 429.

sensors, a continuous hand trajectory does not necessarily produce a continuous frequency glide. Instead, SuperCollider scales the incoming MIDI value into a defined numerical interval and applies rounding, converting the result into a series of discrete pitch positions.

The principal 19-EDO Resonant Piano-Oriented Sound Design (Piano) divides the octave into 19 equal steps and uses 261.63 Hz as its reference frequency. Sensors 0 through 2 each map to 20 selectable integer positions, spanning −19 to 0, 0 to 19, and 10 to 29, respectively. Sensor 3 spans 19 to 45 and therefore provides 27 selectable positions. Frequencies are calculated as:

frequency = 261.63 * (2 ** (step / 19))

A sonic event is initiated when the rounded pitch step changes. Changed.kr detects the transition, while T2A.ar converts the control-rate change into an audio-rate trigger. Remaining within the same quantized region does not generate another excitation. Crossing a region boundary does.

The 21-EDO Multi-Technique String Sound Design (String) applies a comparable process using 21 equal divisions of the octave. Its first three pitch sensors each provide 22 selectable positions, while Sensor 3 provides 27.

The Santur Sound Design in Chahargah uses a twelve-entry ratio array based on D rather than an equal division of the octave. Each of the four pitch sensors selects four positions from a different overlapping segment of the array. The description “Chahargah” identifies the intended modal and compositional reference of the configuration rather than claiming that the software reproduces a single standardized historical tuning.

The 24-EDO Setar Sound Design divides the octave into 24 equal steps. Each of Sensors 0 through 3 provides 25 selectable pitch positions.

In the Santur and Setar configurations, changes between pitch regions are supplemented by proximity-controlled stochastic triggering. Moving closer to a sensor increases the rate of repeated excitation, even when the rounded pitch position remains

unchanged. Continuous distance therefore controls event density, while quantization determines pitch selection.

4.3 - Sound generation and transformation

In the Piano design, Sensors 0 through 3 generate four register-specific resonator voices. Each pitch transition excites a brief noise or crackle signal, which is passed through a tuned comb-delay structure. Reciprocal frequency values determine the delay periods, producing bass, middle, high, and upper-register resonator behaviors. These four voices are combined before further processing.

Sensors 4 through 7 act on the resulting composite signal. An additional variable delay contributes a continuously changing room-like reflection, while a limiter constrains the final output level.

This distinction is functional rather than absolute. In the Setar design, for example, Sensor 6 modifies the pitch behavior of all four string voices through a continuous modulation multiplier rather than functioning only as a post-synthesis effect.

Configuration	Pitch organization	Excitation or synthesis model	Sensors 4–7
Piano	19-EDO	Noise-driven tuned comb resonators	Distortion, reflected delay, chorusing, and stereo movement
String	21-EDO	Ringing, plucked, bowed-oriented, and struck-string processes	Allpass phase processing, diffusion, saturation, and stereo movement
Santur	Chahargah	Repeated noise-driven comb-string excitation	Resonant filtering, allpass sustain, pitch flutter, and stereo movement

Setar	24-EDO	Plucked-string-oriented synthesis with repeated excitation	Body resonance, an allpass drone layer, global pitch modulation, and stereo movement

[**Tab. 2. -** Comparison of the four SuperCollider sound designs (Piano, String, Santur, Setar), showing each design's pitch organization, excitation or synthesis model, and the corresponding transformation behavior assigned to Sensors 4–7. The physical interface, mapping structure, synthesis environment, and performer action collectively define the operative instrument. None of these layers independently determines MAD-X's complete musical identity]

5 - Performance Practice and Gestural Organization

5.1 - Gesture vocabulary

MAD-X is performed through changes in hand position rather than through contact with keys, strings, sliders, or striking surfaces. Its basic gestural vocabulary includes approaching a sensor, withdrawing from it, hovering within a stable region, moving laterally across adjacent sensing zones, activating several sensors simultaneously, and maintaining one gesture while modifying another. These actions become musically meaningful through their assigned mappings rather than through their visible form alone.



[**Fig. 3.** The completed MAD-X instrument, showing the assembled enclosure with the eight exposed VCNL4030 sensing zones arranged in a single horizontal row, ready for performance]

Approaching a pitch-oriented sensor changes the transmitted control value and moves the hand through the pitch regions defined in SuperCollider. In the Piano and String designs, crossing a quantization boundary selects a new pitch position and initiates a new excitation. Withdrawing reverses this movement through the calibrated control range and may pass through additional pitch regions before returning to the inactive area.

Hovering within one quantized pitch region generally maintains the current state without generating another event. The performer must move far enough to cross a region boundary before a new excitation occurs. In parameters mapped continuously, however, small changes in hovering distance may continue to alter delay, modulation, resonance, distortion, or stereo movement. Hovering can therefore function either as the maintenance of a selected pitch region or as the sustained control of a transformation.

Moving laterally across adjacent sensing zones can activate several mappings in rapid succession or partial overlap. In current performance, such movement may produce different pitches and sound effects at the same time, particularly when the hand spans

neighboring sensing areas. The result depends on movement speed, hand position, and the extent to which more than one sensor detects the gesture. Multiple-sensor control also allows several voices or transformations to operate simultaneously.

A further technique involves sustaining one hand over a sensor while moving the other. For example, the left hand may establish or change pitch events while the right hand gradually modifies delay, modulation, timbre, or spatial movement. Repeated interaction with this action-response structure supports the development of embodied and tacit knowledge of the instrument's behavior[20].

5.2 - Two-handed interaction

In the current performance arrangement, the left hand controls Sensors 0–3, while the right hand controls Sensors 4–7. This organization follows the physical division created by the larger central gap between the two sensor groups. The left hand primarily selects pitches or initiates excitations. The right hand primarily transforms the resulting material through effects and broader changes in timbre or spatial behavior.

The two hands therefore assume asymmetrical musical responsibilities. One hand establishes sonic events, while the other alters the conditions under which those events are heard. The performer may initiate a pitch with the left hand and then sustain, destabilize, diffuse, distort, or spatialize the sound with the right. This division supports simultaneous event production and sonic modification without requiring both hands to perform identical functions.

[20] Georg ESSL, Sile O'MODHRAIN, *An Enactive Approach To The Design Of New Tangible Musical Instruments* cit., p. 287.

These assignments remain consistent across the four current SuperCollider environments. They are not, however, permanent properties of the hardware. The roles could be reversed or redistributed by changing the SuperCollider mappings. The present left-right organization should therefore be understood as a practiced configuration rather than as an irreversible feature of MAD-X.

5.3 - Absence of tactile contact

MAD-X does not require the performer to depress a key, strike a surface, or pluck a string. Consequently, there is no mechanical impact or resistance marking the exact point at which a pitch region or effect becomes active. Control is established through listening, visual orientation, spatial memory, familiarity with the sensing distance, and continuous correction of hand position.

Because MAD-X is still a newly completed instrument, I currently rely substantially on the visible sensor openings and central gap to locate the control regions. After a relatively short period of practice, however, the repeated sensor positions begin to support spatial memory, reducing the need for continuous visual attention.

5.4 - Performing changing voices

Loading a different SuperCollider environment does not produce a complete replacement of MAD-X's gestural technique. The four current sound designs follow a broadly shared interaction logic: Sensors 0–3 establish pitch or excitation, and Sensors 4–7 transform the generated material. Approaching, withdrawing, hovering, and moving between sensors therefore remain recognizable across configurations.

What changes is the musical interpretation of those actions. A comparable movement may select a position in 19-EDO, 21-EDO, 24-EDO, or Chahargah. It may excite a resonator, initiate a string-oriented process, alter repeated event density, or produce a different timbral and spatial response. The visible gesture can remain similar while its pitch content, articulation, synthesis behavior, and transformation function change. MAD-X's software-dependent voice therefore emerges through altered consequences rather than through entirely different bodily actions.

6 - Practice-Based Evaluation and Technical Observations

6.1 - Basic technical verification

The completed MAD-X prototype was evaluated through direct monitoring of its MIDI output and repeated performance testing. All eight sensors successfully produced independent MIDI control-change streams, corresponding to CC20 through CC27. Movement above each sensing region generated changes across the implemented control range, and the resulting values were received by SuperCollider without the loss of any sensor channel during the test sessions.

The verification also confirmed that the calibrated range between PROX_MIN = 150 and PROX_MAX = 4000 was usable for the intended hand-distance gestures. Approaching a sensor increased its mapped MIDI value, while withdrawing reduced it until the lower inactive region was reached. Physical movement outside this calibrated range produced no additional control variation because the firmware constrained the values before MIDI conversion.

Stationary hovering did not always produce a perfectly unchanged control value. Small variations in hand position and sensor readings occasionally caused fluctuations between neighboring MIDI values. Because the firmware transmits any value that

differs from the previously transmitted value, even a one-unit change can produce a new message. SuperCollider smoothing reduced the audible effect of some fluctuations, especially for continuously controlled transformation parameters.

Unintended activation of adjacent sensors was also observed. This occurred most often when the hand was wide enough to overlap neighboring sensing fields or when it moved laterally between closely spaced openings. The larger central distance between Sensors 3 and 4 made accidental interaction across the two four-sensor groups less frequent than interaction within a group.

The instrument responded sufficiently quickly for the approaching, withdrawing, hovering, lateral-sweep, and two-handed gestures described in this article.

6.2 - Structured designer-performer observations

The gestures described in Section 6.1 were retested through a short repeated sequence performed with the Piano, Santur, and Setar designs. Boundary-crossing was reproduced reliably when hand movement was deliberate and sufficiently large, and hovering could maintain a selected pitch region, though precise stability required continuous auditory correction. The left and right sensor groups operated largely independently when one hand initiated pitch events while the other controlled effects, but this independence became less precise during rapid or overlapping movements. The absence of tactile feedback was the main source of imprecision, and prolonged hovering produced hand fatigue that further destabilized distance control. Across the three configurations, gestures remained broadly similar while their musical consequences changed, supporting the interpretation of MAD-X as a stable physical interface whose perceived instrumental identity changes through software.

7 - Discussion: MAD-X as an Infraction of the Musical Paradigm

7.1 - Rewriting the means–ends relationship

MAD-X's hardware was not designed after the complete musical structure had been fixed. Instead, the instrument's musical possibilities developed through decisions about sensing geometry, calibration, MIDI allocation, pitch quantization, synthesis, processing, and two-handed interaction. These decisions are technical because they determine how the system operates, but they are also compositional because they define which pitches, articulations, temporal behaviors, and transformations can occur. Such decisions are not neutral technical operations. Sensing and mapping arrangements determine how data become audible, organize forms of listening, and distribute agency among performers, designers, and computational processes[21].

This overlap means that composition does not begin only after the instrument has been completed. Designing a 19-EDO pitch structure, dividing the sensors into event-producing and event-transforming groups, or assigning proximity to stochastic excitation already organizes musical form and behavior. Digital musical systems can therefore function simultaneously as instruments, compositional structures, and performance environments rather than as neutral tools applied after musical decisions have been made[22].

[21] Ali BALIGHI, *Embedding Data into Instruments: An Ethical-Embodied Framework for Electroacoustic Practice*, in «Organised Sound», 2026, pp. 1-2.

[22] Jon DRUMMOND, *Understanding Interactive Systems* cit., pp. 124-125.

7.2 - What constitutes the instrument?

Digital instruments may be analyzed as integrated systems in which interface, mapping, synthesis, and performance practice jointly produce instrumental behavior[23]. Removing or substantially changing one layer alters the resulting instrument, even when the remaining components continue to function.

7.3 - One instrument or a family of instruments?

This configuration-based account creates an unresolved question. Are the four SuperCollider environments different voices of one MAD-X, or are they distinct instruments instantiated through shared hardware?

The physical continuity supports the first interpretation. The enclosure, sensor positions, hand arrangement, MIDI channels, and broad division between excitation and transformation remain recognizable. A performer moving between configurations does not encounter an entirely unfamiliar interface. A developing spatial technique can therefore persist across different tunings and synthesis environments.

The second interpretation is equally plausible. Changing from the Piano design to the Santur design changes the pitch organization, excitation behavior, articulation, and timbral consequences of gesture. Digital systems can retain a physical interface while redefining the constraints and possibilities through which that interface becomes an

[23] Dan OVERHOLT, *The Musical Interface Technology Design Space* cit., pp. 217-219.

instrument[24]. MAD-X can thus function simultaneously as a recognizable physical instrument and as a platform for multiple temporary instrumental identities.

7.4 - From musical object to musical event

MAD-X also shifts attention from music as a stable message transmitted through a fixed instrument toward music as an event produced by changing relationships. It depends on the active software configuration, current calibration, proximity of the hands, quantized pitch position, simultaneous sensor activity, synthesis process, and real-time transformation.

This does not imply the absence of structure. Each configuration establishes constraints within which performance occurs. The musical event emerges as the performer negotiates those constraints through listening and bodily adjustment. Interactive musical systems can therefore blur the distinction between instrument and composition because their operative structures unfold through performance rather than existing solely before it[25].

Conclusion

MAD-X demonstrates that a digital musical instrument need not possess a single, stable voice. A physically consistent enclosure does not guarantee a stable relationship

[24] Thor MAGNUSSON, *Designing Constraints: Composing and Performing with Digital Musical Systems* cit., p. 67.

[25] Jon DRUMMOND, *Understanding Interactive Systems* cit., pp. 124-125.

among form, technique, and sonic identity: because tuning, mapping, and synthesis are reconfigurable in SuperCollider, the same gesture can acquire different pitch content, articulation, and timbre depending on which environment is loaded. Translating continuous proximity data into discrete pitch positions further reorganizes performance around boundary-crossing rather than continuous glide, while the unquantized parameters on Sensors 4–7 preserve a genuinely continuous layer of control alongside it.

This flexibility operates within real constraints. Practice-based testing showed that the absence of tactile feedback left boundaries locatable only through listening and spatial memory, that adjacent sensors were prone to cross-activation, and that prolonged hovering produced fatigue that destabilized fine control. MAD-X's mutability is a designed range of reconfiguration, not an unconditioned openness.

One question is left deliberately unresolved: whether the four SuperCollider environments are different voices of a single MAD-X, or distinct instruments instantiated through shared hardware. Physical continuity and a shared gestural logic support the former; the divergent pitch organizations and timbral consequences of each configuration support the latter. MAD-X is better understood as holding this tension open than as resolving it.

By joining design, composition, and performance in a single practice, MAD-X reframes the instrument not as an object that pre-exists performance but as an event continually produced through configuration, interaction, and listening in practice.

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