Creating a Real-Time Responsive Handbalancing Interface with HAND⋆*CS*

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Figure 1: Performer handbalancing with HAND⋆*CS*.

Abstract

This paper introduces HAND⋆*CS*, a new interface for interdisciplinary expression for music, movement, and light. Our interface augments a pedagogical interface for hand-balancing, Haptics-Assisted iNversions Device (HAND), and transforms it into one for artistic expression. It draws upon Licklider's concept of man-computer symbiosis, specifically the commensalism form of symbiosis. HAND⋆*CS* strives to embody a performance apparatus and system with symbiotic connectivity between performer and interface. This paper discusses the inspiration and background for such a system pulling from the fields of human-computer interaction (HCI), music technology and new interfaces for musical expression (NIME), and circus arts. In addition, it defines the design and implementation, evaluation of the prototype of HAND⋆*CS*, and future work.

Keywords

Circus, Handbalancing, Inversions, Sonification, Performance, Music Technology, Symbiosis

1 Introduction

Interactive interfaces for musical expression often are inspired from musicians' perspectives. As circus artists, musicians, and technologists, we present HAND⋆*CS*, a new interdisciplinary interface for expression that utilizes micromovements within handbalancing to generate music and light. Born from an interface originally designed for handbalancing pedagogy, we describe HAND⋆*CS*'s inspiration, design, and performance application. Using the SensingTex mat [1] as an input controller, HAND⋆*CS* harnesses the pressure array data to approximate the outlines and weight distribution of the hands and then maps the resulting coordinates to sonic parameters in MaxMSP. [2] In addition, wearable myoelectric sensor and LED augmented sleeves visualize the constant effort and microadjustments necessary to maintain even the most "basic" of handstands. We provide a historical background

[1] https://www.sensingmat.cloud/
[2] https://cycling74.com/products/max

on music and circus technology intersections, describe the technical design of each component of HAND★*CS*, demonstrate and evaluate the current prototype interface with a performer, and discuss future directions. HAND★*CS* is yet another interface in the making that embodies our personal motivation and interest in "making the ordinary extraordinary through clever, subtle, and deliberate attention to the integration of movement, music, interactive technology, and light" [20].

2 Background and Inspiration

2.1 Guiding Philosophy

HAND★*CS* is inspired by and named after Licklider's concept of man-computer symbiosis where in his words, two organisms become "heavily interdependent" and "constitute not only a viable but a productive and thriving partnership" [12, 4]. More specifically, HAND★*CS* takes inspiration from the commensalism form of symbiosis, where one organism benefits from a relationship and the other is unaffected [1].

Licklider's two main goals for man-computer symbiosis include integrating computing machines into technical problem-solving and real-time thinking processes [12]. While Licklider mainly focuses on applications with concrete solutions — such as military tactics and hypothesis testing — and fixates on human language communication between human and computer, more artistic applications and alternative modes of communication are left unexplored.

Sonami and Fiebrink embodied the artistic application side of Licklider's man-computer symbiosis through *Spring Spyre*, an instrument meant for symbiotic connectivity with its performer by means of machine learning (ML) [4, 5]. Notably, not only has Sonami stated that she actively collaborates with the instrument itself, but it took her over four years before feeling like she began to understand how to allow the instrument to inform her own creativity. Though this prototype of HAND★*CS* does not yet include ML framework in its mapping, conceptually we are designing HAND★*CS* to inspire interactions and behavior that foster a similar type of creative dialogue between instrument, performer and audience. Furthermore, we plan for HAND★*CS* to be an interface that evolves over a longer period of time, including the incorporation of ML, as discussed in Section 5.

HAND★*CS* is multimodal, combining music, handbalancing and light, and also draws inspiration from Salter's entangled concepts on performance. Salter distinguishes performance from other forms of information-sharing through seven characteristics:

> (1) an interest in enaction or doing, (2) real-time, dynamic processes over static objects or representations, (3) engagement with the temporal moment of the present, (4) embodiment and materiality, (5) immanent experience, (6) the effect of both human and nonhuman presence, and (7) transmutation and reconstitution. [21, xxiii]

Circus arts often engage these characteristics in performance. By incorporating sensors into the performance space, and designing for interaction, performers would be able to better embody these characteristics and explore new entanglements between these elements. HAND★*CS* creates a space to play and engage in these concepts.

2.2 Pioneering Circus Tech

In recent years, there has been a small but growing trend towards interdisciplinary circus research. Relevant works have often focused within the discipline of juggling. These include Reynolds et al.'s responsive environment for the acclaimed Flying Karamazov Brothers [6] using ultrasonic trackers, accelerometer-embedded gloves, and augmented juggling clubs [17], Willier and Marque's technique for jugglers to control sound generation through electromyography (EMG)–though their method didn't support real-time sonic generation [24], and Leischner et al.'s approach using juggling balls augmented with accelerometers, gyroscopes, and WiFi sensors to generate musical output [11]. Within the NIME community, Özcan and Çamcı further explore ideas of playfulness and failure using modified tennis balls with a microprocessor, six degrees of freedom sensor and Bluetooth module to generate music [26].

Ground and aerial based movement circus disciplines have also explored integrating technology and sonic elements. Notably, Elblaus et al. presented three proofs of concept for different modes of sonic interaction within circus arts concluding that "the use of interactive sound in circus is an excellent way to add new channels of expressivity to the communication between performer and audience" [3]. The second author's Sonic Aerialist eLecTrOacoustic system (SALTO), an interactive musical system developed for dance trapeze [18] embodied Elblaus et al.'s quote, giving the dance trapeze artist control over musical expression through an armband containing eight EMG sensors, and a nine degrees of freedom (DoF) inertial measurement unit (IMU).

3 Towards Creating an Expressive Interdisciplinary Performance Interface

Ideally, once a handbalancer has mastered control over their balance from training with HAND, their weight distribution can be used as input control for a performance apparatus. By intentionally shifting weight, the performer could control different events, including sound, visual, or light. HAND★*CS* allows for real-time expression over these audio-visual elements that are typically fixed and cued in circus performance giving the performer almost full creative control. Freeing the performance from strict cues, allows the artist to eschew the mental overhead of focusing on strict timing and choreography. They can better engage with and direct the performance as it currently is developing in the space. To achieve this, HAND★*CS* is compromised of several hardware and software components: 1) the mat (apparatus), 2) HAND (base software), 3) Sound software, 4) Myoelectic LED Compression Sleeves.

3.1 The Mat

The mat used for HAND★*CS* is the SensingTex pressure mat platform "Health Mat Dev Kit 1.9" and can be seen in Figure 1. The mat, which feels similar to a thin yoga mat, has a sensing area of 480 mm by 480 mm containing a 48×48 array of 6 mm diameter sensors with a 10 mm sensor element resolution [22, 23].

SensingTex provided demo software to view pressure distribution, as well as a simple Python [16] skeleton program for obtaining pressure data from the mat sensors.

3.2 The Base Software

The base software was originally written for the Haptics-Assisted iNversions Device (HAND), a handbalancing pedagogy device created by the first author able to correct handbalancing posture in real-time and can be found in Appendix B. In each cycle, the software first runs a k-means algorithm on the data obtained from the mat to determine which points belong to each hand. Using these points, it calculates the current center of pressure between the hands, as well as the ideal center of pressure (assuming equal pressure across all points). Then, the software determines a correction vector from the current center of pressure to the ideal center of pressure.

For HAND★*CS*, the software added a feature to calculate hand boundaries. After determining the points belonging to each hand, the four points containing the most positive and most negative x and y values for each hand are saved. Additionally, the HAND software can provide a real-time visual representation of the pressure matrix (see Figure 2). While useful for the pedagogical tool and early iterations, a pressure-map visualization of a handstand is not particularly interesting on its own for performance and could instead be a hindrance to the performer or distraction to the audience [2]. For the first prototype of HAND★*CS* the correction vectors and hand boundary data were used to trigger and shape sound events.

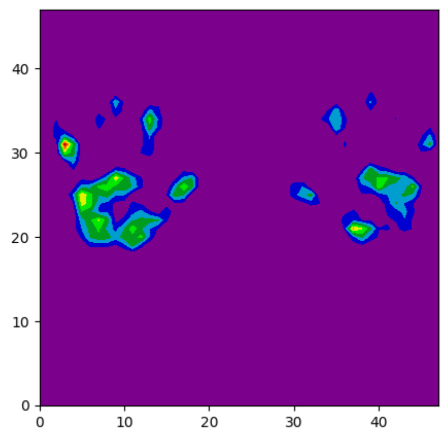

Figure 2: Visualizing the pressure matrix data. Purple indicates no pressure; red indicates highest pressure.

3.3 Sonifying the Handstand

The base software for HAND was augmented to send the SensingTek data to Cycling '74's Max software via Open Sound Control (OSC) messages. The second author then developed the musical interface in Max. After the OSC messages are received in Max they are then scaled to control two different sound modules and a stereo pan slider.

At this early stage, the musical interface elements of HAND★*CS* draw inspiration from previous creative endeavors and the second author's journey as a keyboardist, composer and improviser, combined with the challenge of designing interfaces that convey the broad strokes and subtle details of performance in circus arts. Additionally, the concepts of dynamic and static balance, ideas of effort, pressure and perception are ideas under constant exploration in her work [19]. The sonic elements of HAND★*CS* also draw inspiration from Anthony Braxton's idea of "springboards of musical activity" [25] to create sonic pallettes that performers can start and jump off from.

3.3.1 Mapping. The mapping structure aims to highlight the internal constant presence and energy in static and dynamic movements, as well as the creative dialogue between the performer and the apparatus. A descriptive outline of the mapping is shown in Table 1. The sonic palette consists of both digitally generated and pre-composed and recorded sound files.

Table 1: Overview of sonic mapping for demo version

Variable	Effect
Vx	Pan right
Vy	Pan left
Left Hand (L)	Percussive & organ sound
x_{maxL}	Playback controller
x_{minL}	Pitch
y_{maxL}	Time stretch
y_{minL}	Selection length
Right Hand (R)	Organ sounds
x_{maxR}	Playback controller
x_{minR}	Pitch
y_{maxR}	Time stretch
y_{minR}	Selection length
Hand in trigger zone	Plink tones with reverb and delay

The correction vector used in HAND is used as a stereo pan controller, where the vector's x coordinate corresponds to panning right, and the y coordinate corresponds to panning left to communicate shifting balance. Each cycle, the four points containing the minimum and maximum x and y values for each hand are used as hand boundaries. These points are then used within two primary sound modules: one module focuses on sonifying the data into discrete sound features while the second module focuses on continuous manipulation of a sound feature. When a hand boundary hits a defined threshold, percussive sounds in the plink module and time selections for each of the pre-composed soundfiles are triggered in the Max patch. The second module uses the hand boundaries to manipulate pitch and time-stretch parameters of those pre-composed sound files. The range of max y and min x values for each hand boundary map to pitch and time-stretch parameters.

It should also be noted the first iteration of mapping is catered for demonstration purposes, and will be expanded upon in future work. For this first prototype the thresholds for triggering are arbitrary. This was intended to give a base and wide variety of possibilities as we were learning the range of the SensingTek Mat with one handbalancer. Similarly, the mapping range and scaling is also in the early stages with the same intention of creating a base range to allow for a wider set of sonic possibilities. This range was implemented after observing the sensor output from HAND with our performer for the demonstration video. With continued development the ranges will be fine tuned to achieve more precision and expressivity over the generation triggers and manipulation ranges.

3.3.2 Sound Modules. The plink module, inspired by the MyoWare sensors and pedagogical application of HAND, expands the *orbits* module from *Hollow* [19], "The *orbits* module uses eight impulse generators (click) passed through a resonant bandpass filter (reson~) as well as white and pink noise (noise~, pink~) through a resonant lowpass filter (lores~)" [19]. The eight impulse generator are triggered when different thresholds are met within the eight boundary points. After they pass through the resonant lowpass filter these tones are then sent through a preset pan mixer, delay and reverb modules from Max's BEAP[3] library. The parameters of which could be sensor-controlled in future updates. They function as a constant reminder of the ever-present energy and rhythm of the hands, much like a metronome guiding a musician. This rhythmic quality was deliberately selected for the demonstration to accelerate the performer's learning process of the interface.

The pitch shift and time-stretch module controls four pre-composed sound files, including percussive, melodic and harmonic layers made from metal, wooden, and electric organ recordings. The idea behind merging these elements was to give performers a dynamic soundscape they could control with percussive and fluid changes. The pre-composed sound files are loaded into Max's playlist~object and the *speed* and *pitchshift* messages are modified by the sensor data to stretch and manipulate the pre-composed material. Although the interface only processes data from the hand pressure on the SensingTex mat, it empowers the artist to use their whole body for expressive purposes. As the performer moves their legs, they are instantly making adjustments to their balance and pressure in the hands which is reflected in the boundary data. By leveraging parameters like stereo panning, time stretching, and pitch shifting, there's a dynamic link between the leg sweeps or the sharp bends and precise movements of knees and feet.

3.3.3 Interaction paradigms. This initial sonic springboard aims to set the stage for multiple types of interaction and interpretation from both performer(s) and audience. By embracing the concept of commensalism in symbiotic relationships [12] [1], these sonic elements can be set in motion by the performer or autonomously continue without further intervention. This approach grants the performer flexibility and control — whether they're up in the air initiating sound or descending to transition seamlessly into a grounded move off the mat, the soundscape can persist or pause. This creates opportunities for extended durations of sound or silence, as well as moments of dynamic interaction.

3.4 Lighting Up the Handstand

In addition to sound, we wanted to add a visual component that wasn't reliant on projection and aided our intent of enhancing audience understanding of the effort required to maintain even a "basic" handstand. For HAND★*CS* we also added MyoWare muscle sensors to collect and visualize muscle activation data [13]. The MyoWare sensors are surface electromyography (sEMG) sensors, which monitor changes in electrical activity of the muscle groups they are placed over [14]. Using a compression sleeve, conductive ribbon, snaps, and conductive thread, and referencing a tutorial from the MyoWare website,[4] a pair of reusable performance sleeves were built to each accommodate two MyoWare muscle sensors with LED shields — LED displays built specifically to snap onto the MyoWare sensors [9]. When activated, the target muscles trigger the LED shield to activate a number of LEDs corresponding to the intensity of the signal received (Figure 3).

3.4.1 Placement of the MyoWare muscle sensors. To allow for some flexibility, four muscle groups were prepared as placement sites for the MyoWare muscle sensors: two on the upper arm, and two on the lower arm. Both the flexors and extensors of both the upper and lower arm were targeted, as they control the bending and straightening of the elbow and wrist joints [10].

See Figure 4 for a diagram of conductive ribbon and snap placement for each of the four targeted muscle groups.

Figure 3: Demonstration of the MyoWare muscle sensors with LED displays. At rest (left), not enough muscle activation is detected to light up any LEDs. When flexing the wrist (middle), all ten LEDs light up, indicating significant muscle activity. After the initial activation (right), the muscle signal is not as strong, so fewer LEDs are on.

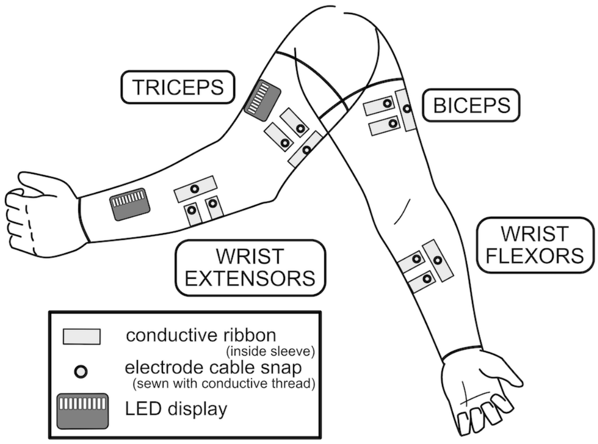

Figure 4: Placement of MyoWare muscle sensor electrodes and LED displays. Note that the conductive ribbon is sewn on the inside of the sleeves. The snaps are sewn on the outside using conductive thread to maintain conductance. The LED displays are mounted to the MyoWare muscle sensor, which are in turn mounted to a cable shield.

3.4.2 Construction of the sleeves. The sleeves were constructed using commercial compression sleeves as the base. Each MyoWare sensor requires three electrodes in the form of snaps. In order to create reusable electrodes, three strips of conductive ribbon per muscle group were sewn onto the inside of the compression sleeves, using the placement determined in Section 3.4.1. To preserve elasticity, alternating cuts were made on the sides of the ribbon (see Figure 5 for a visual). Snaps were then sewn onto the other side of the sleeve using the same placement as the ribbon using conductive thread in order to maintain conductivity. Note that before using the sleeves, the conductive ribbon must be moistened to ensure conductance, similar to consumer electronics such as the Garmin HRM-Dual heart rate monitor [7].

Four pouches were created to hold the MyoWare muscle sensors with both the LED shield and cable shield attached. A rectangle cutout was created to maintain visibility of the LED displays

[3]https://docs.cycling74.com/userguide/
[4]https://myoware.com/project/conductive-fabric-electrodes/

and was reinforced with thread to ensure the sensors would not be able to slip out of the pouch through the display window. Snaps were sewn to the pouches on the top inside rim as closures and to the back as attachment points to the sleeves. Because both the lower and upper arm each have two muscle group options, two display sites were determined to ensure consistency.

Note that the sleeves are sided, as the muscle groups in the left and right arm are mirrored. See Figure 4 for a visual of the LED placement and Figure 5 for a detailed diagram of the sleeve construction.

Figure 5: Overview of the MyoWare sleeves.

4 Development and Demonstration

Before collaborating with a performer, we scaled the data range mapping in Max using our body weight and sample data to establish a base sonic palette. We then asked a trained handbalancer to test and demonstrate HAND★*CS*, as shown in Figure 1. Note that while the different leg positions provide visual interest, the ideal center of pressure between the hands remains the same, as evidenced by the consistency of the shoulder and torso position. Additionally, we further tuned the mapping ranges after a rehearsal with the performer. The demo video URL can be found in Appendix A.

4.1 A Tool for Improvisational Performance

The demo video exemplifies HAND★*CS*'s potential and ease-of-use for a handbalancer. By generating music in real-time, the performer is able to fluidly improvise without fear of missing a musical cue or confusing an accompanyist. That being said, it is important to keep in mind that HAND★*CS* in its current state is a prototype, not a final product.

We asked our performer to write a statement on her experience trying out HAND★*CS*:

> I feel like it was pretty quick to get a gauge of the music side of things and I didn't quite have enough facility to play around with huge differences in weight shifts, but it was super satisfying to feel like the music automatically went with my movements and brought a different element, like a conversation almost. I had a lot of fun trying to figure out the responsiveness of the lights related to the MyoWare — I know part of that is related to my perspective and my area of expertise. I'm already super curious about what muscles are firing in a handstand and then to have a visual representation related to muscles on/off and speed and change of contraction was very neat to explore and definitely something I could feel myself leaning into more. It was nice to be able to "prove" the technology — testing out arm movements just standing and then comparing the lights in a handstand and I was excited to be surprised at which was the dominant muscle based on arm position.
> You know, I think I was maybe fully tuning the music out while I was doing it/it was not very loud if I recall correctly, but looking at the video it definitely feels like I had something to be in conversation with — which even if I don't understand it or feel like I can "control" it is a very fun thing to have as a performer. I feel like in my artistic experiences it is so rarely about control and more about interplay, play, and response. Authentic conversation whether with other artists, space, props, music is a really magical experience. You can definitely be in conversation with fixed music too, but even more enriching, engaging, and exciting when the music talks back to you.

Based on her feedback, 1) the sonic elements must be amplified further in the performance or rehearsal space and 2) interest is perhaps better directed not as a controller/interface but more as a collaborator. The addition of ML, similar to Sonami with *Spring Spyre*, could bolster creativity and lend itself to more of a collaborator role. However, significant time would be needed for an artist to become not only comfortable with HAND★*CS*, but to create a true symbiosis with it.

5 Future Directions

Thus far HAND★*CS* is a promising new interdisciplinary interface for musical and visual expression of circus based movements – beginning with hand-balancing. The interface offers a playground to explore Salter's seven characteristics of entanglement in performance as described in Section 2.1. The initial creative work with HAND★*CS* provided a demonstration and proof of concept. Both developers and performers are still iterating and learning what the system is capable of. There is great potential to keep developing the interface as its only in its infancy. There are several areas of continued development we're considering at this time; performance, accessibility, expressivity and additional collaboration.

5.1 Works in Progress

The first performance piece with HAND★*CS* is currently in development. *Stasis* is a 3-minute-long piece exploring themes of perception, effort and stillness through hand-balancing, light, and sound. *Stasis* exposes the effort required to perform a "basic handstand" and asks the audience to contemplate ideas about equilibrium and the subtle shifts needed to maintain a stillness – though not an effortless one. Jensenius et al. has previously explored this concept — though with upright performers — to research and develop micromovement-based performances [8].

In *Stasis*, an expert handbalancer will perform a straight body handstand with minimal movement; almost imperceptibly shifting their weight to trigger sound and light events. Through weight shifting, the performer will also be involuntarily firing various arm muscles, thereby triggering different visual events. *Stasis* offers a deeper exploration into the expressivity of the sonic elements of HAND★*CS*. By removing the handstand itself from the equation, the audience would be left to engage only with its creations. We plan to premiere *Stasis* in late 2025 or early 2026.

5.2 Porting to an Open Source Language Environment

As mentioned in Section 3.3, the current iteration of HAND★*CS* uses Cycling '74's Max, a proprietary and moderately expensive software system. Furthermore, users of proprietary software are held hostage to vendor upgrades, which are often mandatory, and often break existing codes written using previous versions of the software.

A more attractive alternative, when available, is the use of open source software. For example, Pure Data [15] is free and open source, and would allow for easier collaboration with, and innovation from, other circus artists and musicians. Max was chosen initially due to the second author's familiarity with the software.

5.3 Augmenting for More Expressive Range and Collaboration

As a prototype, the preliminary design of HAND★*CS* was kept simple for feasibility of execution, but there is significant potential for improvement.

5.3.1 Finer control and more complex modulation. Future iterations of HAND★*CS* could expand the HAND algorithm sensitivity to include individual finger control, more nuanced mapping and more precise threshold settings for the sonic elements and further expanded visual patterns generated from the muscle activity on the sleeves. Expanding the algorithm sensitivity to use individual finger control could improve responsiveness, musical range, and expressivity. Additionally, incorporating co-modulation of sound and light events through both the muscle activation and pressure data could provide more meaning to an audience.

As outlined in Section 4.1, the addition of ML could elevate HAND★*CS* such that the apparatus could learn from the performer and vice versa, while facilitating a more dynamic and organic method for calibration. The dynamic aspect of an ML approach to calibration encourages an expressive dialogue between the performer, apparatus and creative output in real-time. It also can be adapted to extend to more than one type of media, e.g., music, lighting, and graphics.

5.3.2 Collaboration. Furthermore, expanding the contextual range to include not only solo handbalancing, but groups of interchanging handbalancers or partner acrobatics acts would amplify HAND★*CS*'s adaptability. Weight limit is of no immediate concern, and supporting a broader range of performance contexts would benefit HAND★*CS*'s performance potential, allowing for more diverse types of performances.

6 Ethical Standards

This work does not have any potential conflicts of interest. Our performer was a willing collaborator and agreed to be filmed. There are no other ethical concerns of note.

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A HAND★*CS* demo video

https://youtu.be/ePlOPTdzB7A

B GitHub repository

https://github.com/linneakirby/HAND

The HAND★*CS* Python module and Max patch are located within the HAND repository.