TUIMotion: Enhancing Sensory Interaction for Individuals with Rhythm Sensitivities

Facilitating inclusive engagement through a multisensory tangible user interface for enhancing participation and interaction in performing arts

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Dance, as a form of artistic expression and cultural communication, relies heavily on auditory cues and rhythm. However, this auditory-centric nature presents significant challenges for those with hearing impairments or challenges in rhythm perception, often excluding them from fully experiencing and participating in dance. This paper introduces a novel Tangible User Interface (TUI) aimed at enriching the sensory experiences of individuals facing these challenges. We utilize an Arduino Uno-based device that integrates vibrational motors linked to wristbands to provide tactile feedback in lieu of auditory cues. Additionally, we incorporated visual and audio-responsive feedback to create an inclusive and engaging environment for users, particularly within dance performances or interactive musical settings. We present a wearable system that examines how users interact to a physical sense of music and use this to redefine interactive experiences in performance arts, to promote inclusivity, and to foster new forms of audience engagement.

CCS CONCEPTS • H5.2 [**Information interfaces and presentation**] User interfaces: Graphical user interfaces, Haptic I/O, Voice I/O

Additional Keywords and Phrases: tangible user interface, dance accessibility, rhythm perception, vibrational feedback, visualization, visual feedback systems, assistive technologies in dance

1 INTRODUCTION

Dance, as emphasized by Rounds (2016) and findings from a Harvard study (2015), transcends its traditional perception solely as entertainment, representing a profound mode of human expression that communicates shared emotions across linguistic barriers [2, 11]. Rounds' work underscores dance as a means of communications, highlighting its intrinsic role in human society via storytelling. Moreover, the Harvard study delves into the cognitive dimensions of dance, revealing its complexity and the resulting benefits, including improved memory, neuronal connections, and a range of cognitive, physiological, and psychological advantages.

With all these benefits, why is that some people just can't dance? Nobody expects a dance floor full of professionals, but scientifically, only an estimated 3% of the population suffer from congenital amusia, or "beat deafness" [6]. Turns out, beat perception is a complicated brain function, according to Patel and Iversen (2014), and through practice, we can train our brain to better predict beats [10].

In this paper, we present TUIMotion, an Ardunio-based wearable device, and discuss the intricacies of our design exploration and decisions. Leveraging vibrational tactile feedback and visual and auditory elements, TUIMotion immerses the user into a multisensory experience to offer a channel for creative self-expression through dance. Issues we address include rhythm perception and hearing impairment challenges to shape new forms of audience engagement and foster inclusivity. Our explorations touch on the broader implications of tangible user interfaces serving to address these issues through visual feedback systems to create multi-dimensional experiences and haptic feedback to coordinate movement, ultimately fostering a collaborative performance.

1.1 Related Work

1.1.1 Tangible User Interfaces

Tangible User Interfaces (TUIs), originating from Ishii and Ullmer's (1997) foundational work on *Tangible Bits*, merge physical and digital aspects to heighten human-computer interaction [5]. Hornecker and Buur (2006) provide a framework for TUI design principles, emphasizing an importance for physicality, embodiment, and expressiveness [4]. Mier's *ChoreoPrint* (2015) showcases a TUI adaptation for dance education, employing an Arduino, force sensitive resistors, and LEDs on an acrylic board to record and replay dance footwork, catering to users across skill levels [8]. ADACHI Tomomi's (2004) Voice and Infrared Sensor Shirt utilizes infrared distance sensors, integrated with Max/MSP audio software, to modulate voice based on body movements during performances [12].

1.1.2 Haptic Feedback

Haptic feedback, highlighted by Di Raddo (2020), offers nonverbal communication in dance, presenting alternative interpretations beyond visual performances [1]. The *Dance Haptics* project by the Deakin Motion Lab with McCormick et al. (2020) sought to build a haptic cushion that translates dance movements to haptic feedback for those who are visually impaired [7]. This required a motion capture system to detect floor patterns that would be communicated onto the audience's back. The biggest limitation of this system is the need to produce quality movements over an 8x8 grid space. Additionally, Gentry's (2005) investigation of haptic communication in swing dance further supports the effectiveness of haptic feedback in coordinating movement in dance, particularly with partners [3]. By analyzing swing dance as a finite state machine, Gentry demonstrates the potential of haptic cues to convey dance moves and facilitate collaborative performance.

1.1.3 Visualization of Music and Dance

Live art visualizations in dance TUIs offer dynamic visual representations, enhancing artistic expression and engagement. Xu's (2021) research highlights digital media technology's advantages, including multimedia experiences and heightened audience involvement, while cautioning about limitations in audience perception and technology-art coordination [13].

Nguyen (2017) found that dancers showed a preference for a visual modality when learning dance [9]. This is primarily the result of dance being a visually-dominant task.

2 IDEATION AND CHALLENGES

Our initial exploration targeted one's perceived confidence in public speaking through hand gestures. Challenges arose due to diverse gesture interpretations across cultures, the complexity of multi-modal gesturing in public speaking, and mixed feedback on the concept's effectiveness. These challenges persisted even after a shift in focus. However, positive feedback on the idea of practicing as a major use case inspired a transition towards performance arts, emphasizing dance as a mode of personal expression. We did not want to focus on being a corrective system. Rather, we wanted to promote confidence in dance by feeling the beat. The goal evolved to enrich personal expression and the dance experience through multi-sensory TUIs.

2.1 Exploring Inputs and Outputs

The TUI system initially aimed to utilize music as the primary input to enhance the dance experience, recognizing music's inherent role in guiding movement. The initial strategy involved using vibrations to represent different musical beats. Separate vibrational motors were considered for bass, snares, and hi-hats, each placed on corresponding body parts. However, this approach encountered issues through user feedback and testing sessions. Testing indicated that while it was possible to isolate individual beats, the resulting tactile feedback was overwhelming. This led to a complexity in touch interpretation that was not present in auditory perception. Moreover, many dance choreographies were found not to strictly follow the patterns of bass, snares, and hi-hats, rendering this categorization too inflexible. The strategy was then simplified to focus on the beats per minute (BPM), using a single, repetitive vibrational output. This approach aligned with the foundational importance of BPM in choreography and addressed the challenge dancers face in maintaining or finding rhythm, particularly when losing track of the BPM during a performance.

2.2 Human Interaction

The exploration expanded to include capacitive sensors for integrating human action as an input and providing immediate feedback. However, utilizing capacitive sensors as proximity sensors proved challenging, with a success rate below 50% and marked inaccuracies. Experiments were conducted with audio feedback that overlapped with the music to augment the auditory experience. However, this approach introduced additional complexity, which conflicted with the objective of simplifying the sensory experience in the context of dancing.

An exploration into visualizing music that dynamically changes with the dancer's movement was undertaken. This method involved using capacitive sensors to detect movement and adjust visuals accordingly. This approach received positive feedback and was found to be intuitive and effective in creating an immersive experience.

2.3 Interaction with a Performance Environment

In building upon the immersive experience concept, the interaction between individual dancers and their environment was examined. The research hypothesized that enhancing audio and visual feedback from both dancers and the audience could significantly augment the overall experience. This led to further investigation into the dynamic interplay of sensory feedback within the dance environment.

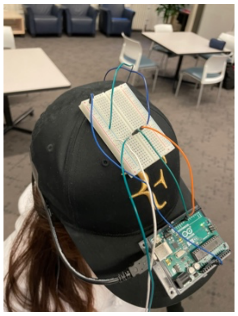

Figure 1: (a) A person wearing the TUIMotion hat that houses the Arduino Uno and breadboard. (b) A TUIMotion wristband with a vibrational motor nested inside.

3 TUIMOTION

3.1 Hardware

The hardware configuration of the TUI consists of a wearable design for immersive sensory interaction to encourage dance. Figure 1 provides a visual representation of the interconnected setup, showcasing the hat that houses the Arduino Uno microcontroller and breadboard as well as the vibrational motors discreetly integrated into wristbands. This hardware directly translates audio beats into tactile sensations.

The core hardware components driving the system include the Arduino Uno microcontroller responsible for controlling vibration motors and a computer running Processing software, generating synchronized visualizations. Additionally, vibrational motors attached to wristbands provide tactile feedback, while wires facilitate connectivity between the motors and Arduino. A hat containing the main electronics ensures portability and houses the system components, integrating technology into a wearable format. Other components include the wristbands serving as mounts for the vibrational motors.

3.2 Prototyping

The device's architecture centers on a wearable configuration, featuring a hat housing the Arduino Uno microcontroller and a breadboard. Wired connections extend from this central hub to vibration motors discreetly embedded within wristbands worn by the user. This setup directly transmits audio beats from the music through the Arduino to the wristband motors to create tactile feedback. Iterative prototyping and programming refinements ensured precise synchronization, providing an immersive experience that encourages rhythmic movements in response to the music's tempo and beats.

Simultaneously, a connected records the user's dance performance through a video feed, processed in real-time with p5.js. The JavaScript library generates visualizations in response to the user's dance movements and the intensity of the audio input, creating a responsive and captivating display synchronized with the music.

3.3 Software

The study implements a visualization system using p5.js, a JavaScript library for interactive graphics. Algorithm 1 demonstrates code utilizing p5.js functions for real-time processing of audio and video input. The setup() function initializes canvas, microphone, camera objects, and a graphics buffer for rendering visual input. Within the draw() loop, randomly scattered ellipses simulate “raindrops,” representing pixels from the captured video. These ellipses’ size and position correspond to video pixel color intensity. Audio input from the microphone influences the visual effect. Increasing audio levels enlarge ellipses, creating a blurred effect, while quieter intervals make the recording more discernible.

3.3.1Directions of the Visualization

The visualization piece aims to serve as a dynamic backdrop within dance performances, offering a unique visual accompaniment synchronized with the movements and auditory elements of a dance. The interactive nature of the system, where audience applause or ambient noise influences the visual abstraction, introduces a participatory dimension to the viewing experience. As viewers engage by cheering or clapping, the resultant blur effect on the backdrop can visually amplify the audience's involvement, creating an interactive, immersive, and inclusive ambiance. This design not only caters to individuals with auditory impairments but also invites broader audience interaction, fostering a heightened sense of connection between the dancers and the viewers. Its potential as a responsive and engaging backdrop introduces a new element to audience-performer dynamics. Audience members are now empowered to collaborate in the experience.

ALGORITHM 1: Digital Rain-effect Visualization

```
let img
var mic
function setup() {
  createCanvas(windowWidth,windowHeight)
  mic = new p5.AudioIn()
  mic.start() // start mic
  capture=createCapture(VIDEO) // set up video capture and create a graphics buffer
  capture.size(windowWidth,windowHeight)
  cacheGraphics=createGraphics(windowWidth,windowHeight)
  cacheGraphics.translate(windowWidth,0)
  cacheGraphics.scale(-1,1)
  capture.hide()
  img = capture;
  noStroke()
  frameRate(120)
}
function draw() {
  noStroke()
  let x = random(img.width) // randomize position within the image
  let y = random(img.height) // randomize position within the image
  colorpix = img.get(x, y) // get color info of image at random pos
  R = random(-100,0) // size
  W = map(R, 0, -100, 25, 0) // map based on random
  M = map(R, 0, -100, 15, 0) // map based on random
  K = map(mic.getLevel(), 0, 0.1, 0, 100) // determine params based on audio input
  noStroke()
```

```
 fill(colorpix, 10)
 /* raindrops based on sizes */
 ellipse(x, y, W, W)
 ellipse(x, y, W*2, W*2)
 ellipse(x+random(-2*W,2*W),y+random(-2*W,2*W),W,random(W*0.9,W*1.1))
 ellipse(x+random(-2*W,2*W),y+random(-2*W,2*W),W/3,random(W/3*0.9,W/3*1.1))
 ellipse(x+random(-2*W,2*W),y+random(-2*W,2*W),W/5,random(W/5*0.9,W/5*1.1))
 ellipse(x, y, M, M)
 ellipse(x, y, M*2, M*2)
 ellipse(x+random(-2*M,2*M),y+random(-2*M,2*M),M,random(M*0.9,M*1.1))
 ellipse(x+random(-2*M,2*M),y+random(-2*M,2*M),M/3,random(M/3*0.9,M/3*1.1))
 ellipse(x+random(-2*M,2*M),y+random(-2*M,2*M),M/5,random(M/5*0.9,M/5*1.1))
 ellipse(x, y, K, K)
 ellipse(x, y, K*2, K*2)
 ellipse(x+random(-2*K,2*K),y+random(-2*K,2*K),K,random(K*0.9,K*1.1))
 ellipse(x+random(-2*K,2*K),y+random(-2*K,2*K),K/3,random(K/3*0.9,K/3*1.1))
 ellipse(x+random(-2*K,2*K),y+random(-2*K,2*K),K/5,random(K/5*0.9,K/5*1.1))
 strokeWeight(W/7) // rain effect
 stroke(colorpix,10) // rain effect
 line(x, y, x+R/2, y+R) // rain effect
 strokeWeight(W/5) // rain effect
 point(random(0,width),random(0,height))
}
function mousePressed(){
 save("tuimotion_backdrop.jpg") // save current view
}
```

Figure 2: (a) An exhibition participant dancing with the TUIMotion device from the front. (b) An exhibition participant wearing the TUIMotion device from the back.

4 EXHIBITION

To best gain insight into the use of the system on those who have a poor sense of rhythm but want to dance, and people in general, a prototype version of TUIMotion was available to demo at a project showcase exhibition for the 2023 course of Theory and Applications of Tangible User Interfaces at UC Berkeley's School of Information (Fig. 2). Attendees could wear the hat and wristbands, dance in the device, and take a screenshot of their visualization on the laptop.

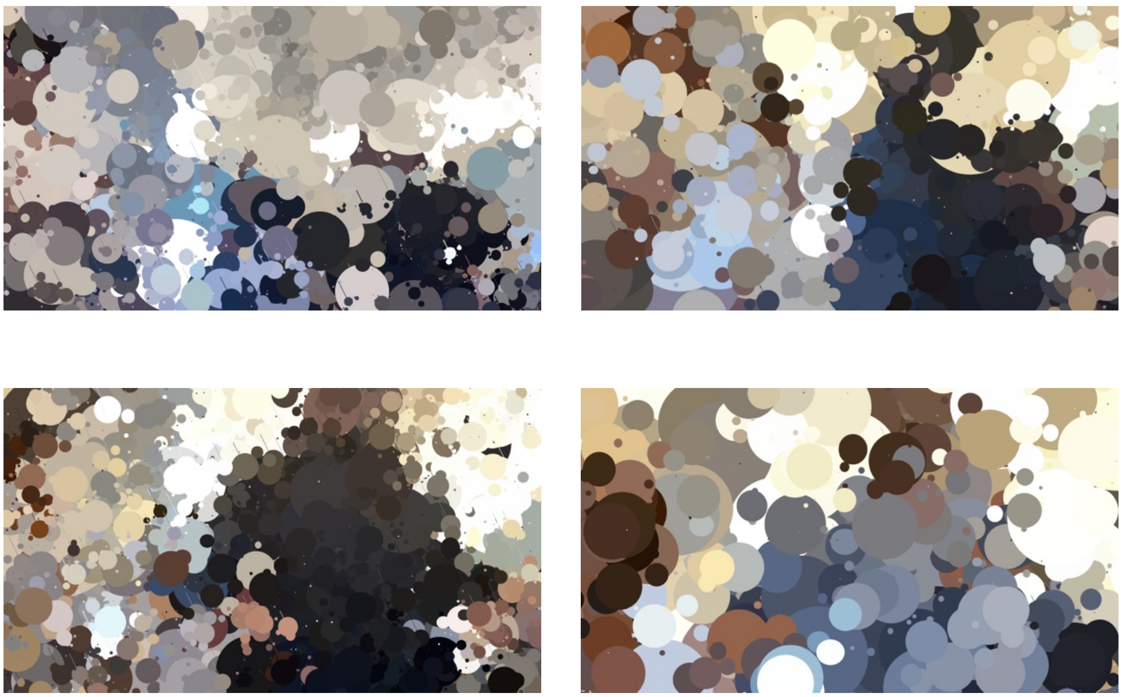

Figure 3: Four saved screenshots of dancing Exhibition participants. The visualizations are created by the code from Algorithm 1.

5 DISCUSSIONS

The exhibition of TUIMotion provided insightful observations into user experiences. Participants were notably surprised by the robustness of the vibrational motors, prompting suggestions for their placement on additional body areas such as the ankles and chest to further augment the immersive experience. As expected, the absence of prescribed movement cues encouraged users to engage in free-form dancing after some initial confusion and shock by the vibrational motors.

The visualization aspect invoked diverse reactions initially marked by some participants' confusion about its representation. However, as participants explored the audio input's influence on visuals, their engagement grew significantly. Users progressively heightened both their movements' volume and dramaticism.

The overall sentiment among participants was overwhelmingly positive, reflecting joy and excitement in trying on the prototype demo as well as receiving a screenshot of their art piece, as shown in Figure 3. Many expressed happiness in dancing to an abstract stimulus, showcasing a departure from traditional dance experiences. This reception highlights potential avenues for future dance interventions in fostering inclusive and immersive experiences.

6 CONCLUSIONS AND FUTURE WORK

In this paper, we introduced TUIMotion, a tangible user interface system transforming dance accessibility. TUIMotion enables immersive engagement through tactile vibrations and collaborative visualizations to encourage inclusiveness in the art, regardless of being correct or on beat. Stemming from our collective passion in enabling arts in different forms, across different genres and for different groups of individuals, our exhibition demonstrates an attempt to unite technology with artistic outlet. Feedback from our exhibition highlighted immediate user engagement, driving future refinements in wiring, portability, and extensive testing. Positive feedback and eager inquiries suggest plans for the team to conduct further field tests to broaden the device's scope and accessibility and advance in our goal of interest to further develop the concept of universality of arts through technology. We hope that future iterations of TUIMotion can consider wearbility on other limbs and take in movement as an input to create more intentional art.

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