# Embodied Movement: Exploring Digital Responsive Interactions

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The project explores the intersection of human movement and digital interaction through a tangible user interface system. Using motion capture technologies and real-time visualization, we developed an interactive platform that transforms physical movements into artistic expression. The system provides two interaction modes: an exploratory mode for general users and an advanced mode for movement practitioners, enabling both accessible engagement and professional use. This research contributes to democratizing artistic expression through technology while maintaining the sophistication needed for professional applications.

CCS CONCEPTS • Arts and humanities Experimentation • Visualization • Physical computing • Performing arts

**Additional Keywords and Phrases:** Contemporary Dance, Motion Capture, Motion Tracking, Interactive Art, Motion-based Interaction, Tangible User Interface, Real-time Visualization

## 1 INTRODUCTION

In the fast-changing world of online technology, physical movement has only recently gained attention as an important field of study. AR and VR technologies have evolved beyond just visual and tactile interactions, now requiring more focus on how users move. Understanding human sensorimotor control is essential for designing better movement-based interactions, especially when dealing with issues like plausibility and long-term adaptation [1].

In a tech-driven world that often values technical skills over intuitive experiences, our research focuses on the connection between physical movement and emotional expression through technology. We aim to create an interactive system that moves away from practical, utility-based designs. Instead, it emphasizes free expression and cultural connection through movement.

Zimmerman et al. [20] present a new model for interaction design research in the field of human-computer interaction (HCI). They advocate a stronger integration of design thinking in HCI research and emphasize the value of artefacts as research results and tools for knowledge transfer. We thus present the research by design artifacts produced through the "embodied movement" project.

We developed an experimental platform using motion capture technologies. This prototype was part of a group project for the Tangible User Interface course in fall semester 2024.

It creates real-time visual feedback based on participants' movements. Rather than conducting detailed cognitive or behavioral experiments, our main goal is to see how removing technical barriers can make artistic expression through technology more accessible to everyone.

## 2 GOAL

Our primary goal is to create an accessible and emotionally resonant interactive system that transforms physical movement into artistic expression. The project centers on the concept of 'Tangible User Interface', investigating how digital systems can translate physical movement into sensory experiences. By removing expertise requirements, we aim to create a system that enables intuitive interaction and spontaneous expression, making interactive art accessible to all participants regardless of their technical background. There is no "right" or "wrong" interaction – instead, we focus on providing moments of release and enabling personal interpretation through gesture-reactive visuals that break traditional structures and patterns.

### 2.1 Research Questions

#### *2.1.1Main Research Question*

1. How does digital movement representation through motion tracking create a new movement quality when translated into art (media art) rather than just movement itself?

#### *2.1.2Sub-Questions*

1. How do technological interfaces alter participants' spatial experiences?
2. How does movement tracking influence participants' emotional responses?
3. Can digital art disrupt the participants' reality and expand a user's daily repertoire of mobility? 4. How to make movement-based visual art accessible?

## 3 CONCEPTUAL FRAMEWORK

Tangible User Interface (TUI) bridges the digital and physical worlds, providing intuitive interaction with digital information through physical objects. [16] TUIs offer diverse applications, including education, medicine, music, and museum installations. They have especially shown potential in enhancing collaboration, learning, and design [6], while also particularly enhancing aesthetic experiences. Despite their potential, developing TUIs remains challenging due to the technical expertise required. Key characteristics of TUIs include the integration of physical and digital representations, physical control, and underlying digital models. [18]

Klemmer et al. [12] have shown the significance of the human body for the design of interaction systems. They especially highlighted: "thinking through action", "performance", "visibility", "risk" and "dense practice". According to their research, taking physical interaction into account leads to more innovative and user-centered designs that better integrate the physical and digital worlds. "Thinking Through Doing" describes how physical interaction with the world enhances our cognitive understanding. Also, gestures not only support communication, but thinking through movement. Their study shows that gesturing reduces cognitive load and helps people to express thoughts that are difficult to put into words. Tangible interfaces that involve the body and especially the hands can improve the reliability of interaction. Another aspect is muscle memory: movement sequences are stored in muscle memory through repeated physical action. This "kinesthetic memory" is reliable and robust, but only used to a limited extent by traditional GUI interfaces. Special physical actions for various interface functions could make better use of muscle memory and make interaction more efficient. Given that starting point and relevance of body movement as Tangible User Interface, we are interested in the relation between the body movement and aesthetic representations of movements. We decided to focus on movement aesthetics as an avenue for exploration. The research delves into how a TUI, understood as an artistic installation, can reveal alternative ways of experiencing movement quality [19]. Our approach deconstructs traditional interaction paradigms by eliminating prescriptive interaction models through prioritizing fluid, interpretative experiences and removing linguistic and technical barriers to engagement. The research methodology embraces a post-structural approach to interaction design, characterized by non-hierarchical interaction models with an emphasis on emergent, participant-driven experiences and a rejection of binary conceptualizations of "correct" interaction. The fundamental hypothesis posits that technological interfaces can function as generative platforms for personal and collective emotional expression, rather than mere instrumental tools.

## 4 INSPIRATIONS

Starting from the research question of how digital movement representation through motion tracking, when translated into digital art rather than just movement itself, creates a new movement quality, we gained some inspiration from existing media art projects.

1. "The Inheritance" Story, Dance, 3D Printing, Real-time Motion Capture, Stereographic Projection, 3D Interactive Image, within a historical Architecture, displayed 2015 in Beijing [7] [8]. Here especially, the meaning of wide-ranging movements in a large space alongside aesthetics serve as inspiration, as well as the artist's interest in departing "from storytelling to story-living, contemplating how to experience narratives through immersive and interactive means."
2. "Farbklangschichten" [11] explores kinesthetic experiences with different colors and sounds. KAE is a media artist from Indonesia, who combines in her installation's movement, layers of color, algorithms and piano sounds. In this exhibition people can play, make music and experiment.
3. "Colored Shadows" explores how colored shadows of movement representation dance along with the user. Exploratorium Museum Exhibit. 2024 [4]
4. "The Treachery of Sanctuary (2012)" was an exhibition by Chris Milk who utilized 3 large panels and motion tracking technology to showcase users as shadows which would change into birds if the right movements were used. [14]

## 5 METHODOLOGY AND ADJUSTMENTS

To conduct our targeted research, we first engaged in extensive discussions using the 'Scenario' method from IDEO Model Cards [10] to identify specific use cases and potential users. For example, we established several scenarios by considering factors such as dividing groups into dancers (representing "skilled" movement) and public ("non-specialist" movement), potential environments (both indoor and outdoor), and factors like group versus individual interactions. During this process, practical limitations such as the constraints of installing media outdoors were also considered. Furthermore, we utilized speculative design methodology [3] and Tarot Cards of Tech [17], particularly the "Catalyst" and "Smash Hit" cards, to anticipate potential obstacles and undesirable outcomes through the taxonomy of futures. The goal of this method lies “not in trying to predict the future but in using design to open up all sorts of possibilities that can be discussed, debated, and used to collectively define a preferable future for a given group of people: from companies, to



cities, to societies” [3]. Through these various factors and experimental methodologies, we developed a media art prototype focusing on crowd movement interaction.

## 6 DESIGN PROCESS

### 6.1 Development of User Scenario

Two distinct interaction modes have been conceptualized:
Exploratory Mode (Preliminary User Interaction): Designed for non-specialist participants, this mode facilitates intuitive engagement through simplified movement interactions, enabling broad accessibility and initial system exploration. Advanced Performance Mode: Targeted at professional movement practitioners, this mode provides granular shadow representations and generates specialized biomechanical feedback, supporting nuanced movement analysis and refinement. By examining the intrinsic and extrinsic factors that inspire bodily movement, we seek to uncover novel insights into the complex interplay between individual motivation, interpersonal communication, and self-expression through physical engagement. Through this research, we aim to create user experiences that motivate and bring joy to participants.

### 6.2 Development of Visual Design

By utilizing the multi-step approach with gesture recognition, edge tracking and motion tracking, we imagined several visual representations, both for the recognition of body parts as well as for movement. These visual representations were designed to effectively support the two interaction modes described above. Specifically, we decided on a fluid approach that moves away from realistic body representation, allowing users to interpret and express their movements more freely.

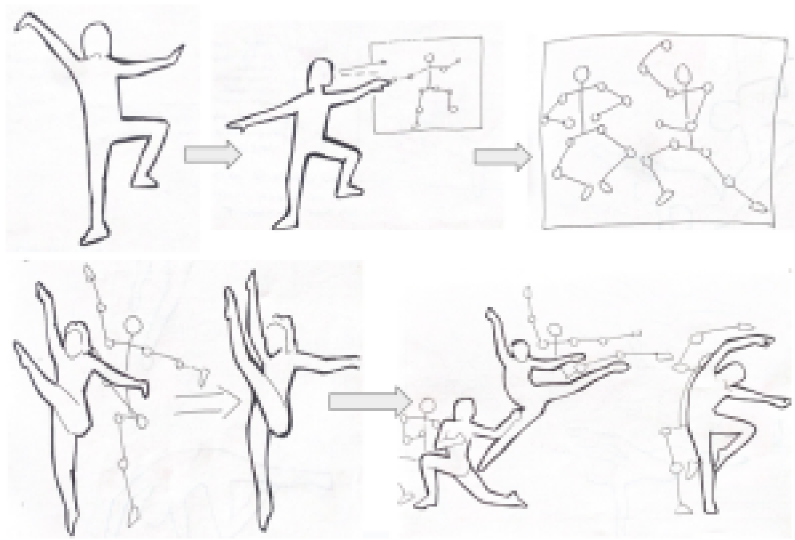

Figure 1: Scenario for Professional Dancers



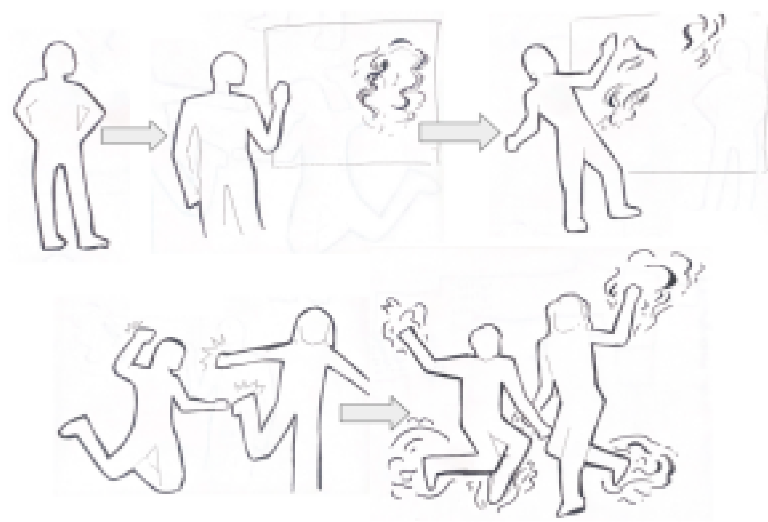

Figure 2: Scenario for Casual Dancers

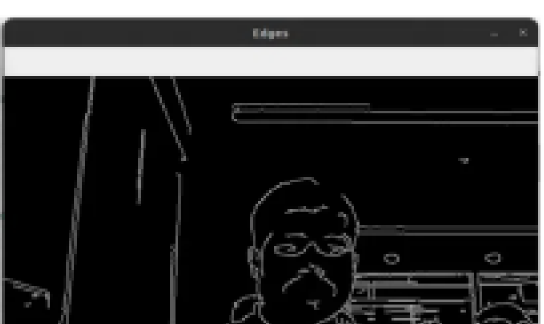


Figure 3: Method of Realistic Edge Detection

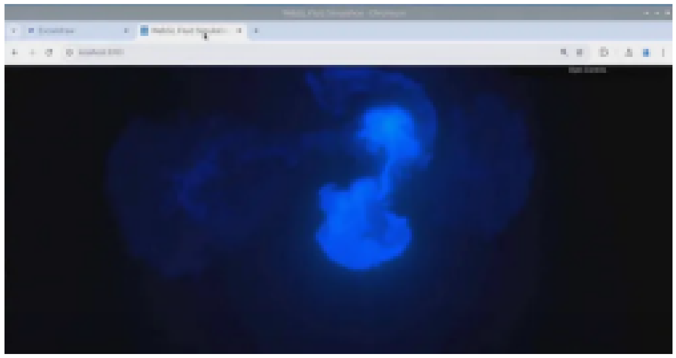

Figure 4: Fluid Design Approach

## 7 INTERACTION MODEL

Software capabilities allowed for one or multiple users to interact with the TUI. When a user interacted with the TUI independently, they had full control over the design. Whereas when multiple users had their gestural data tracked, an average value was computed to modify the point cloud design. This TUI interaction required users to collaborate and compensate for space within the range of the camera to produce visuals that best represented their combined movements.

## 8 PROTOTYPING TECHNIQUES

### 8.1 Pose estimation with Movenet and DepthAI

We used OpenCV (version 4.5.1.48) and DepthAI (version 2.9)

The Movenet model is a pose estimation model developed by Google Tensorflow for detecting human body key points [9]. It identifies key body joints such as the nose, shoulders, elbows, and knees. We mapped human body keypoint names



to their indices. We used it to detect 17 body keypoints and the nose as a central keypoint location. Theoretically, the model can track multiple people simultaneously. It turned out to be sporadic and created an unintended, but interesting, artistic effect of people deciphering their visual representation from others.

For support of the pose estimation, we used DepthAI: An AI/computer vision platform for deploying neural networks on edge devices (OAK-D cameras). The Movenet-DepthAI class is designed to detect human body poses in real-time using neural network models, it supports multiple input sources: RGB camera, video files, images, and webcams. We used a Kinect Camera as an input device. The DepthAI Integration was used to reach a low latency pose detection, support memory management, and directly run neural network execution on devices. This approach leverages the OAK camera's dedicated neural computing capabilities for efficient, real-time pose estimation.

### 8.2 Accelerometer: Tracking acceleration and height of movements

An accelerometer ADXL345 and Arduino Nano were used as an alternative tool to modify digital media outputs based on sensor inputs. The accelerometer tracked velocity and acceleration across the x-, y-, and z-axis. Using serial data from the device, the digital values were communicated to the TouchDesigner file. Various elements were modified to alter the visual, including the period, amplitude, and exponent of the point-cloud visualization. For example, if the accelerometer were attached to the user’s hand, having them lift their arm would produce a linear increase in values, thus increasing the  amplitude of the visual.

### 8.3 Visualization

TouchDesigner [2], a node-based visual programming software, was used to create point-cloud visualizations modified by  serial data of the accelerometer, as well as gesture-tracking data from Movenet. The design is a geometric, point cloud  visualizer that emulates "breathing" movements reflective of the user's gestures.

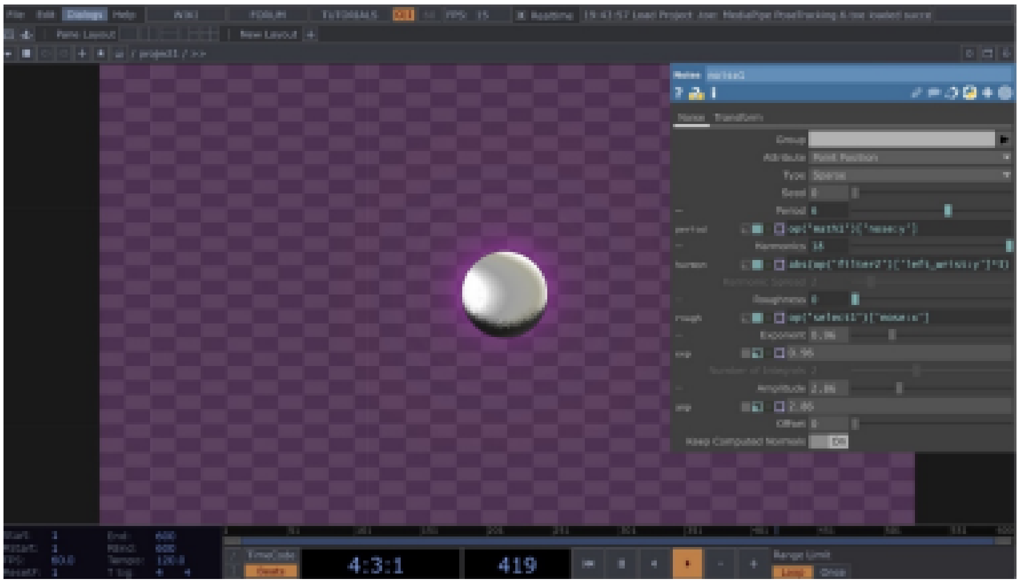


Figure 5: Initial TouchDesigner Design



## 9 EVALUATION

Sengers and Gaver challenge the traditional HCI approach that favors a single designer-dictated interpretation of computer  systems [15]. Following their framework, which advocates for multiple possible interpretations, we adopted an evaluation  strategy that encourages diverse user interpretations rather than enforcing a 'correct' one. This approach emphasizes user  autonomy and participation in understanding technology. Based on this, we conducted a user-centered qualitative  evaluation during our Tangible User Interface showcase, focusing on both individual and group meaning-making  processes, including assessments of dance quality and technical aspects such as extensibility, transparency, and  documentation.

## 10 USER CENTERED EVALUATION

During the showcase presentation, we observed users engaging with the system through exploratory movement patterns. Our system, built with TouchDesigner, Movenet, DepthAI, enabled interaction through user movement tracking. Users demonstrated varying approaches to interacting with the system, from simple gestures to more complex movement sequences, and the body movement mapping encouraged experimental engagement. While our observations are preliminary and would benefit from more structured evaluation, these initial observations provide insights for future iterations of the system, particularly in areas of movement tracking precision and visual feedback mechanisms.

## 11 DOCUMENTATION

The conceptual and technical aspects of the project are described in this paper, with additional **code** and files provided online and on Github [5] [13].

## 12 NEXT STEPS AND FUTURE DEVELOPMENTS

Future development can focus on two main areas. In technical aspects, we aim to enhance the digital interaction system by refining how physical movements are translated into dynamic visual responses, as well as advancing our methodology for tracking multiple participants simultaneously. Additionally, we plan to improve movement tracking precision to capture more nuanced gestures. For interaction aspects, we intend to expand our media interaction capabilities by incorporating diverse visual and auditory elements, while developing a broader range of user experience scenarios that can accommodate different contexts and user preferences.

## 13 CONCLUSION

This research explores the creation of an accessible interactive system that transforms physical movements into artistic expression through tangible user interfaces. Our work suggests the potential of digital systems to translate movement into meaningful sensory experiences while maintaining accessibility for users regardless of their technical expertise. By prioritizing intuitive interaction and spontaneous expression, we aimed to develop a space that breaks away from traditional "right" or "wrong" interaction patterns, offering personal interpretation and emotional release through flowing visual responses. The educational implications of our work extend beyond the technical aspects, contributing to broader discussions about democratizing interactive art and creating more inclusive technological experiences.



## 14 ACKNOWLEDGMENTS

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