The Australian National University
2600 ACT | Canberra | Australia

School of Computing

College of Engineering, Computing and Cybernetics (CECC)

Touching Wires: Exploring Tactility in Human-AI Musical Co-Creation

— Honours project (S1/S2 2024)

A thesis submitted for the degree
Bachelor of Advanced Computing

By:
Sandy Ma

Supervisor:
Dr. Charles Martin

October 2024

Declaration:

I declare that this work:

- upholds the principles of academic integrity, as defined in the University Academic Misconduct Rules;
- is original, except where collaboration (for example group work) has been authorised in writing by the course convener in the class summary and/or Wattle site;
- is produced for the purposes of this assessment task and has not been submitted for assessment in any other context, except where authorised in writing by the course convener;
- gives appropriate acknowledgement of the ideas, scholarship and intellectual property of others insofar as these have been used;
- in no part involves copying, cheating, collusion, fabrication, plagiarism or recycling.

October, Sandy Ma

Sandy

Acknowledgements

Entanglement was a concept that kept resurfacing this year. My practice, my being, and by extension this project is a culmination of everything and everyone I have experienced until this point.

On 4 September 2024, I wrote “What would my grandmother say if I told her I was an artist?”. It was a jarring thought as she had passed almost 15 years ago, and I wasn’t particularly close, nor kind to her as a child. I wonder what she’d make of my silly little practice when she had raised 6 daughters during such a tumultuous period in China. This question led me to think about all those who have nurtured me and those before them.

I would like to acknowledge the academics and educators who have shaped my knowledge and guided me through this lifelong journey of learning. Thanks to Charles for his continuous support to do silly things and validation that I am still contributing to computing.

Thanks also to all the people who have offered their time, energy, and generosity in the last six years, including but not limited to -

- Isobel and Tess for editing through this thesis.
- Seb for giving me stability and cooking for me.
- Mao and Casemiro for staying healthy all year.
- Hash, Lav, Sasha, Kat, Isaac, and Brenda for their patience and kindness.
- Isabelle for sharing their kindness, soul and energy with me in our 4A performance.
- Yichen and Minsik for feeding me Korean food and letting me distract them in the office.
- the artists, educators, and artist educators who have instilled in me the confidence to identify as an artist. Maggie, Emma, Lucky, and Andrew - the artists who I want to be when I grow up.
- and everyone else who has contributed to my past, and my now.

I would also like to acknowledge the Ngunnawal and Ngambri people, whose lands I have had the privilege of living, working, and growing on for the past 6 years. That acknowledgement also extends to the Dharug people and the Gadigal/Bidjigal people of the Eora Nation whose unceded lands I grew up on and first fostered my passion for learning. First Nations knowledge is integral to the development of sustainable science and technology, and I am so very grateful to be in communities where I am able to learn from my First Nations friends, colleagues, and leaders.

Abstract

Tactile interaction is a cornerstone of how humans build relationships in the world, including those we create with computers and machines. This thesis details the development of a textile-based musical performance system integrated with machine intelligence to form sonic dialogues between human and machine. We use this system to explore tangible and embodied interactions within human-AI interaction.

This work introduces a quilted interface that allows users to control a digital synthesis instrument based on the Bela audio platform. Configured as an interactive call-and-response interaction with machine-generated output, we investigate the role of soft textile interfaces in navigating relationships between human users and computer systems. This has been explored through autoethnographic data collated from the researcher's perspective in performing with the system, as well as user study data from participants interacting in a controlled environment.

The development process of the system has been documented within this thesis, and results have been collected and analysed to evaluate the role of tactility in human-AI interaction. We find familiarity and communication as key themes in human-AI interaction. Tactility, sight, and audio all form integral access points to forming embodied understandings of novel systems. Textiles are an underexplored and novel way of inviting users in to explore interactive experiences and media.

Keywords:

human-AI interaction, e-textiles, creative computing, practice-led research, tangible and embodied interaction.

Terminology & Acronyms

The following is a list of terms and abbreviations used in this thesis.

AI	artificial intelligence.
DIY	do-it-yourself.
HAII	human-AI interaction.
HCI	human-computer interaction.
NIME	new interfaces in musical expression.
Pd/pd	PureData; a visual programming language developed by Miller Puckette for creating interactive computer music and multimedia works.
TEI	tangible and embodied interaction.

Table of Contents

Chapter 1

Introduction

Tactile interaction is a cornerstone of how humans build relationships in the world, including those we create with computers and machines. Physical interactions between humans and machines have been long defined by rigid materials—rocks and minerals encased by more rocks and metals. With the increasing presence of artificial intelligence (AI) in creative practices, critical reflection on the relationships and definitions of collaboration with AI agents is required. Additionally, as AI develops as a potential co-creator and collaborator, we must challenge the abstraction of technology from its materiality.

This thesis details the development and use of a textile-based musical performance system (Figure 1.1) integrated with machine intelligence to form sonic dialogues between human and machine. This work introduces a quilted interface that allows users to control a digital synthesis instrument. This artefact facilitates an interactive call-and-response interaction with machine-generated output. Through this system, we investigate the role of soft textile interfaces in navigating relationships between human users and computer systems.

Our project finds that tangible and embodied interfaces provide a physical access point for humans to become active participants in human-AI co-creation. Textiles are an underexplored way of inviting users in to explore interactive experiences and technologies. Joy and fun in finding new forms of interactions encourages users to be curious about the systems and technologies they are faced with. Additionally, we found that users desire a familiarity with the context of the system before wanting to form decisions on trust. Machine generated outputs give human users a reliable source of inspiration and material to experiment with.

Figure 1.1: *Touching Wires* at 4A Lab Opening Night Performance (10 October 2024)

1.1 Background

Familiarity and physicality underpin tangible computing and the development of embodied interfaces (Dourish, 2001). This familiarity with technology is usually found in metals and hard plastics; this project posits the need for softness and intimacy as we build trust to create transparency in our technologies. To do this, we use textiles as a basis for familiarity for new forms of expression and collaboration with AI. This project aims to fill a research gap at the intersection of tangible interfaces, artistic co-creation in human-AI interaction, and interactive audiovisual systems.

Current research on human-AI collaboration and co-creation manifests through either the visual in two-dimensional drawing and mark making activities, or sonic and music making systems (Martin and Torresen, 2019; Davis et al., 2016; EL-Zanfaly et al., 2022). Furthermore, understanding and trust are a current research focus in human-AI relationships (Ghajargar et al., 2021). However, there is little research directed at tangible and embodied interaction with AI in contexts of musical and artistic performance.

Thus, our overall goal is to further understand the effects of soft materiality as a novel medium for interaction with AI. The insights gained throughout this project will help us produce better frameworks for designing and understanding human-AI co-creation in artistic contexts.

1.2 Motivations & Specifications

When negotiating the parameters of this project with my supervisor, the only requirement specified was that I would create a system using the Bela audio platform—a software and hardware environment extension built upon the BeagleBone Black development board (Moro et al., 2016).

My work and practice has always been defined by the goal of sparking curiosity and joy in the people around me. As an educator and artist, I hope to break down barriers to digital literacy and understanding technology in ways that are playful and bring enjoyment. Play is a fundamental part of both adult and childhood learning (Whitton and Moseley, 2019) and it is therefore a powerful tool to connect non-technical audiences to technologies like AI, and perhaps even demystify them. This project investigates human-AI interaction in a time where the term "artificial intelligence" has seen rampant and careless overuse to capitalise off audiences who are attracted to the black box that can seemingly solve all the world's issues (Linthicum, 2023).

Thus, the artefact at the core of this project was to be a musical performance system with the following specifications:

- **be large**: Embodied interaction is defined by use of the body and large scale interfaces which produce distinctive relationships with the body (Mice and McPherson, 2022). Therefore, the interface I wanted to create should allow performers to engage their bodies.
- **be tactile**: Defining tactility as a formative goal for this project allows us to continually consider how this interface is helping us bridge understandings of AI and new technologies and answer our key research questions around trust.
- **be fun**: Joy engages people to further explore and interact. I wanted to create an artefact that had longevity beyond this Honours project, and thus defined fun and joy as a goal to be able to refer back to the question—"will I enjoy the outcome of this decision?".
- **incorporate both machine and human input**: Centring both human and machine input in the system allows us to focus on the human-AI interaction.

Over an 8-month period between February and October 2024, this project created a large musical quilt integrated with an AI agent for collaborative performance.

1.3 Research Questions & Findings Summary

The following research questions situate this project within HCI and computing academia:

- ***What roles could tangible and embodied interfaces have in human-AI co-creation?***
  Tangible and embodied interfaces mediate meaningful interaction by inviting the

user as an active participant with their own agency. Making the abstract tangible allow us to clarify our understanding of the differing roles in human-AI collaborations.

- ***What do textile interfaces enable in digital musical instruments?*** Textiles bring novelty, fun, and embedded intimacy into systems and instruments made for performance. The inherent associations with textiles offer an immediate access into users' comforts.

- ***How can embodied human-AI interactions enable trust?*** Multi-sensory embodiment offered by tangible and embodied interaction afford users the agency to choose how to participate and collaborate. This agency encourages trust as humans are able to form deeper familiarisation with AI systems.

1.4 Methodology

This project gathered data from my (the researcher's) own practice, and external perspectives from user study participants. Employing methodological triangulation (Blandford et al., 2016) on these two approaches helped validate the findings from each method.

1.4.1 Practice-led Research

Undertaking practice-led research (Nimkulrat, 2010; Candy, 2006), this project gathered data through my personal artistic practice and reflections in designing, rehearsing, and performing with the interface. Three presentation instances were formative to the reflective process:

- 30 May 2024: Solo performance at ANU School of Music
- 5 September 2024: Work in progress demo at the NIME Conference (Utrecht, Netherlands)
- 10 October 2024: Installation, exhibition and performance (human duet + AI) at 4A Lab gallery space

These performances provided valuable opportunities for critical reflection and introspection. The insights gained from these experiences informed both the iterative design process and the reflective writing that accompanies practice-based research.

This methodology acknowledges the researcher's practice as a valid component of HCI, emphasising the importance of personal experience in understanding user engagement with interactive technologies (Neustaedter and Sengers, 2012). Reflexive writing (Joshi et al., 2024) played a crucial role in this process. After each presentation, I documented thoughts, observations, and emotional responses, allowing for a deeper understanding of the interaction between performer and interface. This reflexivity was essential in shaping the direction of the project and identifying key themes that emerged from both personal experience and audience engagement. Practice-led research was a suitable methodology as this project has an "interplay between human culture and physical materiality" (Brown and Sorensen, 2009).

1.4.2 Thematic Analysis

User study sessions were conducted in a controlled environment to gather data from random participants' perspectives. Thematic analysis as defined by Braun and Clarke (2006) as the process by which data is first coded whereby patterns within the dataset is collated, then analysed to identify themes. Interpretation of these themes were then discussed in relation to the research questions. The thematic analysis provided a framework for understanding user experiences and interactions with the interface, highlighting patterns that emerged across different participants. Braun and Clarke have reviewed the application of this methodology again (2019), and again (2021).

Through thematic analysis, the project aims to bridge the gap between artistic practice and user experience, providing a nuanced perspective on the interplay between technology, performance, and audience interaction. The findings from this research will contribute to ongoing discussions in HCI, particularly regarding the role of personal narratives and user-centred design in the development of interactive systems. In this project, we will follow the methods articulated by Braun and Clarke (2021).

1.5 Ethical Considerations

As technology makers interacting with people and users, it is integral to critically engage with the ethical considerations of the work we do.

Throughout this project, sustainability has driven the material choices and production methods. Efforts have been made to minimise waste in the making process, and to reuse where possible.

The energy consumption of contemporary technologies has been a topical discussion. Therefore, this project has depended on the use of small form embedded computers, reducing the energy usage and minimising the computational power necessary to reach our goals. By prioritising sustainability, this project aims to foster a more responsible relationship between technology, its makers, and its users, ultimately contributing to a more conscientious and engaged community of creators and participants. Section 2.2.2 articulates the current literature and discourse surrounding technology, material, and ethics.

For the user study sessions in October, random participants were invited to engage with the project. They provided consent to audio and video recordings, and observational notes were taken by the researcher. The ethical aspects of this study were approved by the ANU Human Research Ethics Committee (Protocol 2024/0995), and participants were fully informed of the implications of their engagement. Submitted documents can be found in Appendix A.

1.6 Thesis Outline

This thesis will summarise the project activities and findings.

Chapter 2 reviews the current literature to contextualise this project.

Chapter 3 describes the system design process from the initial prototype to its final iteration.

Chapter 4 outlines the findings and evaluations of this project.

Chapter 5 discusses the findings by responding to the research questions.

Chapter 6 concludes this project and outlines future directions and opportunities for the work presented in this thesis.

Appendix A contains the documents submitted and approved under ANU Ethics Protocol Number H/2024/0995. Appendix B highlights links to audiovisual documentation of performance instances described in this thesis.

Chapter 2

Contextualising Tactility in Human-Machine Musical Co-Creation

Revolutionary textile artist Anni Albers said, "we touch things to assure ourselves of reality" (Albers, 2018). Tactility in human-AI musical co-creation touches on varying bodies of literature. This chapter will contextualise the project in contemporary research in HCI, and related interdisciplinary fields.

We start by considering the history and development of digital musical instruments, and their most recent evolution toward embedded computer music systems. From here, we situate the role of embodiment within digital musical instruments, and explore tangibility and materiality within technology. Contemporary materials for making and manufacture are informed by various ethical issues. In this chapter we highlight how they are entangled in our technological practices. Finally, we explore the current literature on human-AI trust and interaction with respect to collaborative and co-creation contexts. Each field explored below are interdisciplinary both internally, and externally in their relations to other disciplines.

2.1 Designing Musical Instruments

Artistic practices have always been dictated by the tools and technologies afforded to the artist. Likewise, sound and music making are dictated by the instrument provided to the musician. With the introduction of electricity and electronics, makers in the 20th century started to experiment with new possibilities in instrument design offered by the electrical (Miranda and Wanderley, 2006). As we continue down a path of rapid technological development, new ways of designing and making are pushing the boundaries and definitions of a musical instrument.

2.1.1 Digital Musical Instruments

Digital musical instruments (DMIs) are systems or artefacts where sound is generated by way of digital sound synthesis. DMIs consist of controls which drive the musical parameters of a sound synthesiser in real time. As DMIs developed throughout the late 20th century, the term "electronic music" became encompassing of any sound content that combines traditional and/or electronic instruments with a wide range of acoustic processing equipment to enhance playback and listening, whether live or on a recorded medium (Réveillac, 2019). Today, DMIs exist in many forms. Novel physical interfaces have been explored such as magnet instruments (Lepri et al., 2024), motion stick instruments (Malloch and Wanderley, 2007), stretchy fabric controllers (Chang and Ishii, 2007)). Classical instruments have been augmented such as clarinet and flute feedback systems (Panariello and Percivati, 2023; Memis et al., 2024)). Instruments have also been designed for virtual realities (Wang and Martin, 2022; Camara Halac and Addy, 2020). This project will focus on novel physical interfaces, centred around delivering tangible and embodied experiences for users.

2.1.2 Embedded Computer Music Systems

As digital musical instruments began branching out into new design philosophies, many makers saw the potential for embedded computing music systems to provide cheap and compact options for independent instrument creators. The International Conference for New Interfaces in Musical Expression (NIME) hosts the largest gathering of such makers, and has mapped the development of embedded computing options in DMIs throughout its proceedings.

Researchers have continually sought for ways to streamline designs for both hardware and software in embedded computer music systems (Schmeder and Freed, 2009). Early examples of these systems include the Satellite CCRMA (Berdahl and Ju, 2011), which migrated the sound synthesis to a Beagle Board-based embedded platform. Further abstraction toward independent embedded platforms for musical instruments developed as Berdahl, et al., continued to implement networking and graphical output capabilities to the Satellite CCRMA platform (Berdahl et al., 2013).

By 2016, the Bela (McPherson et al., 2014) platform introduced an embedded platform for low-latency interactive audio that was based on the BeagleBone Black board. The Bela team's support for a graphical language like PureData (Puckette, 1996) increases accessibility for music makers to explore embedded systems and novel sensors. The development of the Bela enabled NIME researchers to create more complex systems of digital musical instruments, taking advantage of its low-latency audio processing. Gonzalez Sanchez et al. (2018) use the Bela platform to create a collection of digitally-controlled augmented acoustic guitars.

Today, researchers are still radicalising embedded musical systems by creating new interfaces (Snyder and Polito, 2024), and embedding machine learning (Visi, 2024)—even on the Bela platform (Pelinski et al., 2023).

2.1.3 Embodiment

Computer interfaces have been defined by hand interactions—keyboard, mice, buttons, knobs, etc. Within HCI, embodied interfaces are defined by forming an interaction with and understanding of the computer system through the body. Mice, et al. posit that "interface designers have a responsibility for people's bodies" as they form an extension of the performer (Mice and McPherson, 2022). Large scale interfaces produce distinctive relationships to the body, inviting users to consider the use of their entire body. Mirando defines manipulative gestures in DMI design as those "whose purpose is to control some entity by applying a tight relationship between the actual movements of the gesturing hand or arm with the entity being manipulated" (Miranda and Wanderley, 2006). Extending the gesture beyond the hand through large scale interfaces instils agency into users to choose their nature of interaction.

Dourish (2001) defines embodiment as possessing and acting through a manifestation in the world that extends beyond just the physical. Embodiment is thus the cohesive experience between our own senses and the world around us.

2.2 Tangibility & Materiality

"The more touch is impossible, the more one wants it and appreciates how vital it is to our being."

- Richard Kearney (2021)

Familiarity and physicality underpin tangible computing and the development of embodied interfaces (Dourish, 2001). As technology further abstracts tangible experiences, we must revisit how tactile experiences and materiality foster better connections with novel concepts. Our bodies know that video calling is a digital abstraction for face-to-face communication; we know that a text message replaces vocal and verbal words—but how do we recognise the tangible experience of making digital sounds and communicating with an AI entity?

Pigrem (2022; 2018) found that materiality is a key aspect in expectation of both gestural interaction and sonic response in DMIs. When introducing sound into an interaction, the designer must present cohesion between the sonic and the tactile in order to allow users to identify a causal relationship. When designing controls for interfaces, Zheng (2022) found that spongy materials encouraged pressing gestures leading to continuous control.

2.2.1 Entangled Textiles

Textiles define our analogue worlds and identities; textiles form our clothes, our bedding, our flags, our couches and so on. Therefore, the integration of textiles with technology seems to be a natural progression. The concept of e-textiles—or textiles incorporating electronics—has seen a growth in the community of DIY makers and repairers, and seen applications in rehabilitation, affect and event detection, as well as soft robotics (Skach et al., 2018). While textiles are a flexible, intuitive material for human interaction—appropriately adopted by technologists—the familiarity and unconscious association invites users to be curious and consider how technologically charged textiles may challenge their assumptions and expectations.

With the recent application of entanglement theory into HCI (Frauenberger, 2019), researchers have sought to articulate the relationship between the body and the machine through post-humanist or 'more-than-human' theories and frameworks (Morrison and McPherson, 2024; Kannabiran, 2023). As technology increasingly integrates with textiles, it is important to consider how textiles currently influence our everyday experiences and interactions with technology. The comfort and softness of textiles offer a new way to engage with technology. By incorporating this unique quality into our interactions with new systems, like AI, we can better understand how we form relationships with novel technologies and autonomous systems.

2.2.2 Material Politics

Technology is built on human labour.

Human labourers are paid pennies to process hateful content to retrain OpenAI's ChatGPT (Nyabola, 2024), to collect and annotate data for facial recognition software used for surveillance (McIntyre et al., 2024), and are exploited and endangered in the production of hardware (The Research Centre for Gender, Family and Environment in Development and IPEN, 2017). The lack of transparency in making processes have dehumanised the supply chain and manufacturing, abstracting the human hand on our everyday clothes and items away from public consciousness. Exploring textiles and technology in tandem exposes their overlapping ethical concerns and allows us to critique contemporary systems and practices.

Since the industrial revolution, many have feared and criticised the removal of human handicraft and labour from production practices. William Morris, a socialist textile artist and a pioneer of the British Arts and Crafts Movement, argued that the industrialisation of crafts primarily serves "the profit of the capitalist," asserting that the will of craft artists "[have] no part in their production" (Morris, 1888). Thus, handicraft on an individual level is viewed as a proactive act against capitalistic systems by making clear the human intent. Practices in textiles therefore carry the histories and connotations of craft and hand labour.

As we move into the 21st Century, contemporary concerns with textiles persist through the lens of production, consumption, and waste. Textile over-consumption and waste issues pose a threat to environmental sustainability (Wojnowska-Barya et al., 2024). 'Fast fashion' industries capitalise off of peoples' ignorance and apathy towards the human rights abuses and environmental impacts (Papasolomou et al., 2023) of their practices for capital-driven greed. The human hands behind fashion industries are discarded and obscured to drive profits and consumer ignorance.

When we examine the technological revolution of today, the same criticisms of dehumanised and abstracted practices persist. Child workers are often exposed to the unsafe work conditions that plague the cobalt mines required for lithium-ion batteries used to power our rechargeable electronics (Kara, 2023). Global technology company Samsung was found to be exploiting their predominately female labour (The Research Centre for Gender, Family and Environment in Development and IPEN, 2017) workforce in Vietnam, and were also responsible for environmental pollution from improperly disposed chemical waste (Lee et al., 2024). Within realms of DIY electronics and novel interface designers, the practice of hacking and making your own solutions is inherently political by way of rejecting mass-produced technologies, and its associated shortcomings.

Through active consideration of the ethical implication of our work, technologists are able to provide further critical and transparent examinations of the impacts of their products. With the increasing accessibility of AI, there is also a growing desire to analyse the social and environmental impact of these models (United Nations Environment Programme, 2024) and how they can shape better making practices.

2.3 Human-AI Interaction

Human-AI interaction research has emerged to reflect on the growing integration of artificial intelligence (AI) into daily practices—from the medical, to academic, and even creative. Perceptions of AI vary from anthropomorphised entities to electronic devices (Hwang and Won, 2022). Therefore, relationships with AI can vary in terms of more humanistic dynamics to hierarchical dynamics where users may view the agent as a tool rather than a collaborator (Lawton et al., 2023). Much like human dialogue, directionality of communication matters in forming a perception of AI agents (Ashktorab et al., 2021). Berkel, et al (2021) define continuous human-AI interaction as systems that 'listen' to a stream of uninterrupted user input rather than individual instructions and can respond to this input throughout the duration of the interaction. Continuous human-AI interactions best suits tasks that involve exploration and discovery, allowing users to surrender some control, especially with complex interfaces (Gammelgård-Larsen et al., 2024).

2.3.1 Creative Co-Creation

Methods of creative expression and story telling have always reflected the technology of their time and the introduction of AI into creative realms has seen practitioners explore the potential for agents to be collaborative partners. The rise of autonomous systems in creative practices requires critical reflection and discussion to define the role of generative systems and, by extension, the role of the artist in these collaborative relationships.

Margaret Boden (2015) defines creativity "in the broadest sense ... [as] the ability to generate new forms". When discussing creative thinking, Tony Proctor (2021) posits that "any definition of creativity is complicated because the concept is multifaceted". Therefore, we will approach creativity from a computational perspective for this project.

Historically, computer-aided creativity has inserted the role of the computer as a tool. However, as the machine begins to assert more autonomy and agency, creativity breaks beyond the boundaries of human cognition. Frieder Nake (2014) posits that "algorithmic art starts with the development of an algorithm. That's human work".

Thus, defining creativity in this space reduces to the ability to create. Creative practice and artmaking can then transcend towards creating 'something' to connect with an audience—the kind of connection is therefore up to the maker and their intent. If the intent of the machine is to generate output that closely fits the model it has been designed to do, there is valid metric for measuring its creativity. When exploring human-AI co-creation, it's essential to focus on the experiences of both the machine and the human. We should critically examine the relationships that develop among all participants by identifying shared elements in the creative process and understanding the intentions behind their contributions.

Human-AI collaboration and co-creation currently manifests through either the visual in two-dimensional drawing and mark making activities, or sonic and music making systems (Davis et al., 2016; EL-Zanfaly et al., 2022; Martin and Torresen, 2019). With the increasing presence of artificial intelligence in creative practices, critical reflection on the relationships and definitions of collaboration with AI agents is required. If we define creativity as the ability to create with conscious intention, co-creation is therefore its output with multiple agents and their abilities and intents. Moura asserts that in human-AI co-creation, "the forms of autonomy may be shared between humans and AI to varying degrees, to shape the final creative output" (Moura, 2024). Thus, the result of this collaboration is defined not by the comparison of intent or autonomy, but by the interaction and relationship formed during the process. There is little research directed at tangible and embodied interaction with AI in contexts of musical and artistic performance. Relationships of understanding and trust with AI (Ghajargar et al., 2021) is a current research direction attempting to articulate this gap, however, lacks the intimacy and reflexive nature performance and creative practice offers.

In response to the industrial revolution, Walter Benjamin's iconic 1935 essay "The Work of Art in the Age of Mechanical Reproduction" criticised technologies and tools of reproduction for removing the agency of the artist into a mechanical process. Exploring human-AI co-creation places the human as an active participant in the process. This allows us to better define the role generative tools and machines have in our daily lives through articulating our relationship, and identifying our needs for AI.

2.3.2 Trust

Trust is a formative aspect of any relationship, hence it is a useful metric for codifying human-AI co-creation. Quantifying emotional and relational interactions through nonverbal communications may provide further insights into user's trust in AI systems (Berkel et al., 2021). Furthermore, Zuckerman et al. (2022) found that users configured in turn-taking actuation with AI experienced it as competition rather than collaboration. Therefore, maximising trust in a system requires consideration of not only the nature of interaction but also the context it exists within.

Relationships take time and effort to evolve, and human-AI relationships are not an exception. Relational trust between two people can be defined as a belief about the other person's trustworthiness with respect to a matter that emerges under conditions of unknown outcomes (Robbins, 2016). Within the bounds of human-AI co-creation, we can extend this definition to the belief about the AI's trustworthiness to create, to contribute, and to collaborate.

2.4 Related (Art)Works

Skach et al. (2024) surveyed the NIME archive and provided an overview of the work on non-rigid interfaces within this community. They assert that textile interfaces for musical expression should be guided by three considerations:

- Exploit the affordances of different sizes as bigger interfaces are easier to make in textiles.
- Gestures should directly align to the sound output.
- Quality of the interaction over the quantity of sensors.

Through this framework, we point to the following works that relate to or have influenced the output of this project.

Prior to starting this project, I was working on Unspoken (2024) (Figure 2.1), a mixed reality duet where I controlled a digital synthesiser through analogue drawings, fed through an image classifying model. Through this work, I was captured by the role of tangible interactions and gestures in artistic communications. How do we reconcile tactile and analogue interactions within digital realms and spaces?

This work was built on communicating through gesture but ultimately, did not represent gesture sonically. Sounds were generated based on the image classifier, which emphasised a disconnect between the interface and the sound system. Thus, this highlights the importance of aligning gesture with the sound output that Skach et al. allude to.

Artefacts like EJTECH's 2023 *Dung Dkar Cloak* (Figure 2.2) bring this tactile and analogue interaction into the e-textiles discourse. The work's touch sensitive interface differentiates the amount of touch to alter the soundscape. The large scale and installation of the work invites audiences to investigate, and the sonified interaction allows audiences to recognise their controls. The scale and material connotes a sense of comfort, something rarely explored in computer interfaces.

Figure 2.1: Still from *Unspoken, 2024*, mixed reality duet performance by Sandy Ma and Yichen Wang

Figure 2.2: *Dung Dkar Cloak, 2023*, woven e-textiles by EJTECH

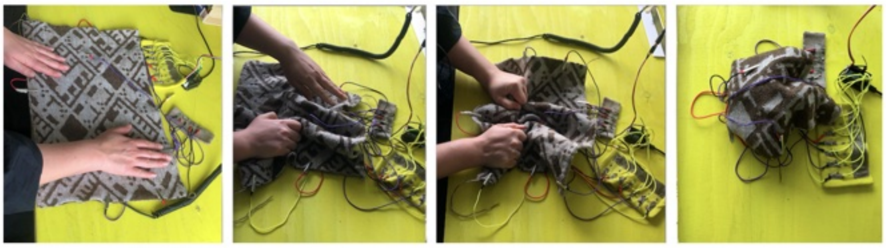


Figure 2.3: *Knitted Mat, 2024*, woven e-textiles by Sophie Skach, Victor Shepardson, and Thor Magnusson

Skach et al. (2024) introduce their *Knitted Mat* (Figure 2.3) that incorporates conductive material within the fabric of the interface. This artefact highlights the diverse potential for textiles as a medium for electronic interfaces.

Furthermore, the small scale of the work invites hand-based interaction, illustrating the association between scale and nature of embodied affordances. E-textiles offers a flexible medium for musical expression, with historical and social connotations that offer audiences a safe and intimate atmosphere to explore.

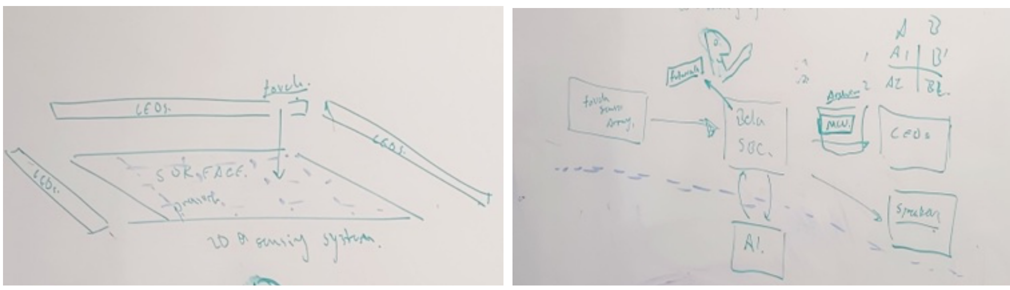
Chapter 3

Creating a Human-AI Musical Co-Creation System

At the core of this project is a textile-based musical performance system—colloquially referred to as "*Touching Wires*". This chapter describes the making and design process of this artefact. Section 3.1 outlines the iterative making process of the three components in this musical system: the textile interface for human input, the audio-visual output, and the integration with machine generated input from an interactive musical prediction system (Martin and Torresen, 2019) that uses a mixture-density recurrent neural network. Section 3.2 describes changes made to prepare the system for installation and public interaction.

Based on the specifications discussed in Section 1.2, a system design diagram was conceived by the end of week 3 (Figure 3.1).

Figure 3.1a describes the physical set up of a 2D tactile interface, surrounded by LED lights to visualise the affects of the user's interaction. This also allows a visualisation



(a) System Layout (b) System Design

Figure 3.1: Whiteboard diagram from project meeting (7 March, 2024)

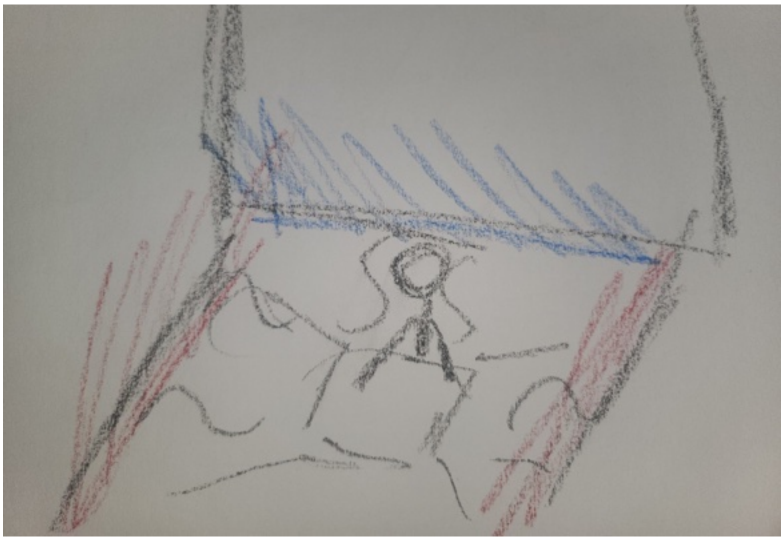


Figure 3.2: First concept drawing of musical performance system (20 March 2024)

for the integrated AI output. Figure 3.1b outlines the logistics of the system design, whereby the Bela board is at the core of the system's control.

3.1 System Design & Creation

The *"Touching Wires"* system features three components: a sound synthesiser, a textile interface for human input, and a musical prediction system as an AI agent within this system.

3.1.1 Making a Musical Tablecloth

This section describes the decisions and process of creating the first prototype of the physical interface element of this system. Designed around the Bela Trill Craft breakout board that has 30 channels for novel touch interfaces integrated on the Bela Mini—a Bela fitted on a PocketBeagle whose primary advantage was its smaller form factor. Initial decisions around using copper tape to create tactile sensors were inspired by Trill Craft tutorials (bela.io). The initial conceptual drawing (Figure 3.2) featured a flat tabletop interface that would connect to LED strips visualising the AI agent's actions and presence. This was done also to further the tangibility of autonomous digital systems.

Experimenting with copper tape (Figure 3.3) highlighted its sensitivity and reliability when interfaced with the Trill Craft. During this time, I had also successfully used a Pd patch that generated simple tones based on the detection of capacitive touch.

When presented with options for interfacing with the Bela, my supervisor provided various Trill sensor options. Discussions and ideas around the Trill Craft bore ideas of

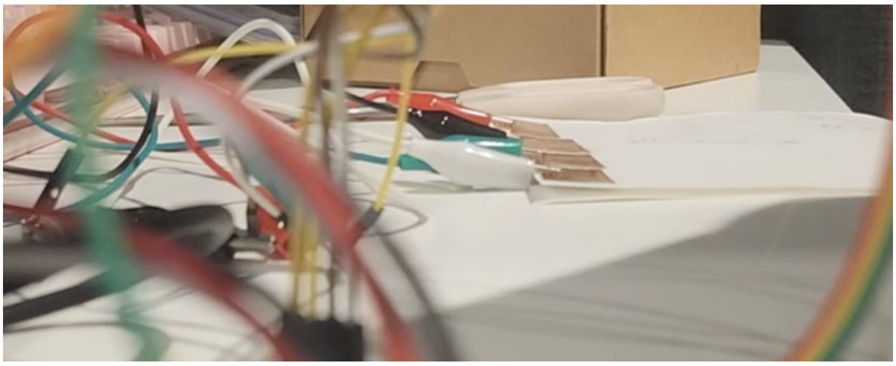


Figure 3.3: Copper tape experiment as touch interface (22 March 2024)

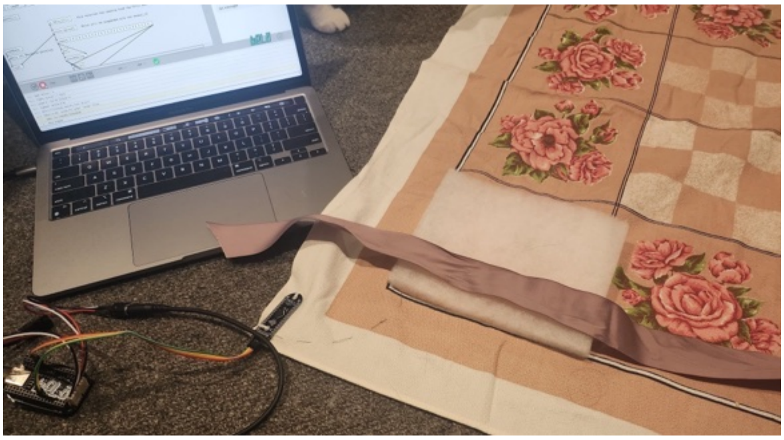
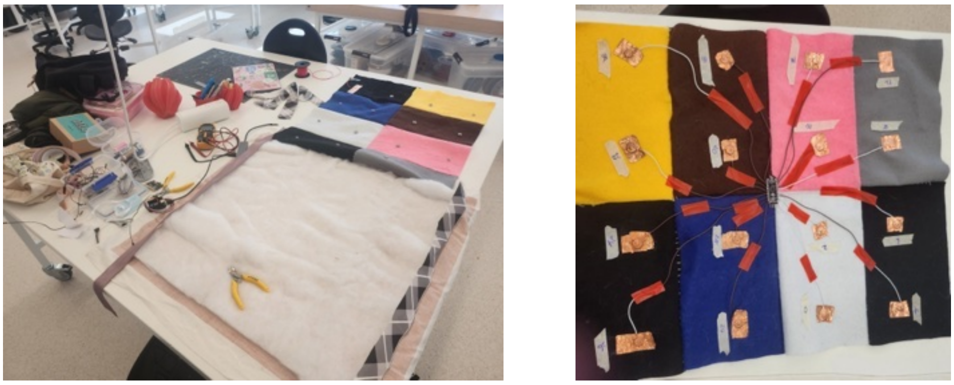


Figure 3.4: Experimenting with fabrics, wadding, and conductive thread (25 March 2024)

textiles and sewing. The Trill Craft also allowed for more flexibility in terms of creating a new large scale interface as I could dictate the size and design more easily.

I chose to experiment with conductive surfaces within fabric interfaces as a way to explore soft materiality when interacting with computer systems—an interaction long defined by hard minerals encased by more metals and rocks. Conductive thread was experimented with to further remove the solid and hard material from this system. Wadding allowed for more discrete control in the motion captured. During this time, a second-hand tablecloth had been procured from a Red Cross charity shop to form the basis of the interface (Figure 3.4). It was selected for its size, and imagery that outlined a 4x4 square grid.

Using second-hand fabrics sourced personally or from charity shops was a priority in the making of the textile interface to promote an ethical and sustainable practice. The underlayer (Figure 3.5b) was created using rectangular felt sheets used in a previous project hand-sewn together. Button clasps were sewn onto the felt as conductive buttons



(a) Fabric layers (11 April 2024) (b) Circuitry layer (23 April 2024)

Figure 3.5: Interface Construction

to situate the sensors and help secure the wiring. Although conductive thread was a suitable option, we found that the simpler and cheaper option was to solder wires onto the Trill Craft to form the underlying circuitry.

At this stage, I had a working musical blanket that had 16 sensors where each generated a sine tone at a different frequency (Figure 3.6).

Making Sounds; Visualising Sounds

With a functioning interface, focus turned to the design of the audiovisual output of the system. The synthesiser element forms the audio-visual output of this performance system and runs on the Bela board. Sound synthesis occurs via a Pure Data (Pd) patch (Puckette, 1996) that generates tones and plays samples based on the capacitive input from a Bela Trill Craft sensor, and visual output was built with the p5.js JavaScript library (The p5.js Team). From 9 May-22 May 2024, the focus of this project was on stabilising the system's Pure Data patch and P5 sketch.

Both Pd and p5 accept an array of 16 input values from the Trill Craft. Due to the nature of the Bela and its interactions with P5 and Pd, the Pd patch initiates all operations on the Bela.

Setting the Trill Craft occurs within the Pd patch via the provided functions from Bela (Figure 3.7).

The array of 16 input values from the Trill Craft are sent to the Bela GUI that runs the p5 sketch via the Pd patch. The array of 16 is prepended with a '0' buffer number (Figure 3.8) to ensure separation between messages (bela.io).

Making Sounds

The initial prototype with 16 tones generated used the Bela Trill Pure Data tutorial patch (bela.io). While the sensor was stable, the sonic output had clicking/crackling

Figure 3.6: Complete Prototype (2 May 2024)

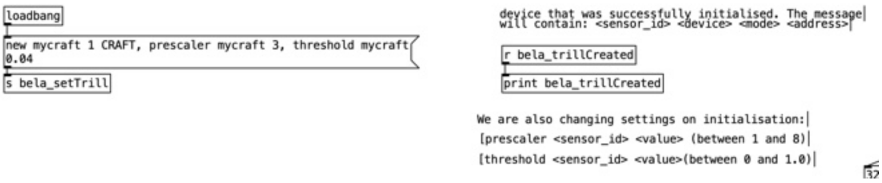


Figure 3.7: __main.pd patch—initialising Trill Craft

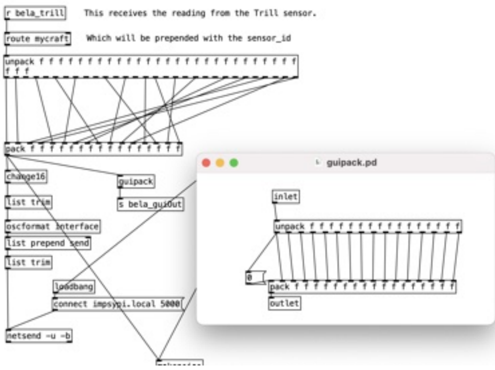


Figure 3.8: __main.pd and guipack.pd patches—GUI interaction from Pd patch

Figure 3.9: Bela IDE view project settings for sampling rates (15 May 2024)

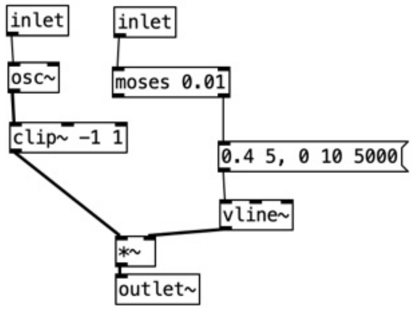


Figure 3.10: doot.pd patch (15 May 2024)

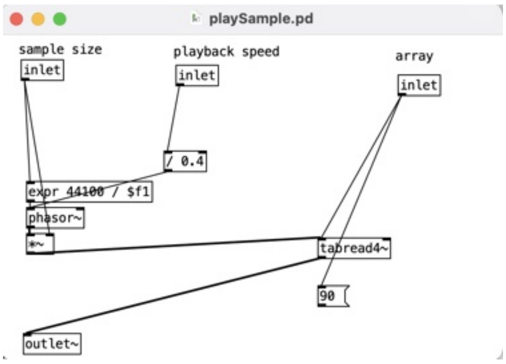
noises scattered throughout. After desperate experimentation attempting to envelope sounds and smooth output to deter the crackling, a forum post (2018) guided me towards changing the hardware settings on the Bela. Extending the audio frame block size from 16 to 128 and increasing the analog sample rate to 44100Hz stabilised the output and removed the crackling noise (Figure 3.9).

During a meeting with my supervisor and Dr Alexander Hunter from the ANU School of Music, both commented on the need to extend the diversity and complexity in sound design of the instrument as sine tone oscillators did not offer enough to the performer.

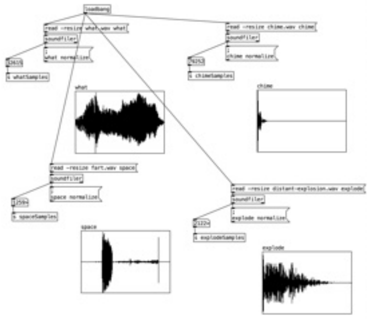
Following this conversation, enveloping and reverb effects were added to the sine tones generated. First, the tone generation was abstracted into a separate Pd patch to make it easier to use across multiple tones titled ‘doot.pd’ (Figure 3.10)—referencing the style of noise I observed. The left inlet of ‘doot’ took in a frequency that would be fed into an oscillator object, and the right inlet would trigger the envelope. Enveloping was implemented by adding a Pd ‘vline’ object to create an ADSR (attack, decay, sustain, release) pattern whereby the sound is incrementally amplified and then released.

Sample playback was implemented to further diversify sonic output. Samples were collected from both online (Melia, 2019; radian, 2008; carlos kamas, nd) and personal (Ma, 2023) sources. Capacitive input from the Trill Craft determines the playback speed of the sample to enhance embodied experience as there is direct changes observed to the audio output based on user movement.

The makenoise Pd patch (Figure 3.12) handles all sound generation. The first four



(a) Playing back samples



(b) Loading Samples into arrays

Figure 3.11: Sampling in PureData

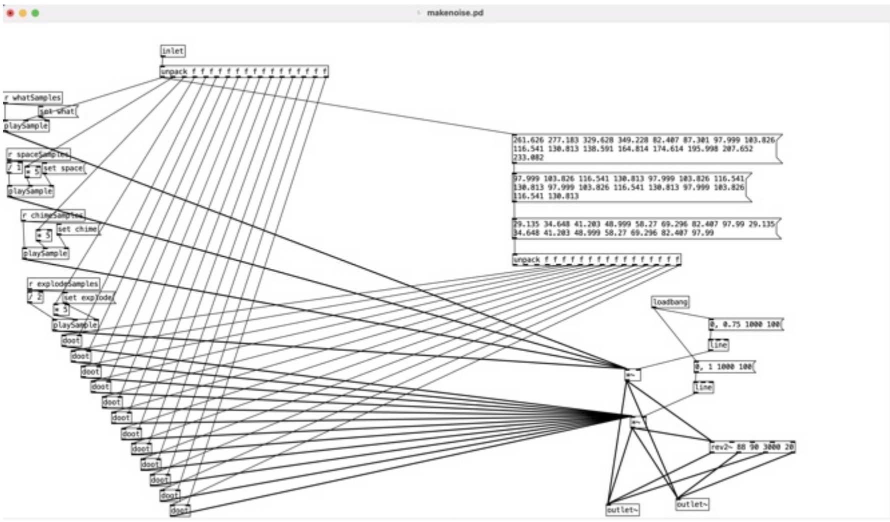


Figure 3.12: makenoise.pd patch

sensors play samples using the playsample.pd patch (Figure 3.11a), and the last twelve sensors trigger oscillators at different frequencies. These frequencies have been manually programmed.

Visualising Sounds

Visualisation has been a crucial element since the inception of this project as I had wanted a way for users to identify the effects of their actions. Attempts to use LED lights at the beginning of this project were abandoned as the harshness of the LEDs did not complement the soft textile interface. Following that, I made the decision to explore a visualisation in p5.js with the intention of it to be projected to amplify the lightness that complements the fabric surface.

The P5 sketch was designed to replicate the 4x4 grid of the physical sensor. To add

Figure 3.13: p5.js sketch output during performance (30 May 2024)

dimensionality and visual interest, blob shapes (mcpecommander, 2020) would be drawn and the size of each blob would be determined by its assigned capacitive sensor value. When performing with the first prototype at the ANU School of Music, I had decided to stream webcam footage of the physical interface underneath the blob drawings to allow audience members in the flat venue to see the floor-based interface. The position of the blobs were inverted from the sensors to allow audience members to see the physical input alongside the visualisation. Figure 3.13 is a screen capture of the p5 sketch during the performance.

3.1.2 Making a Musical Quilt

Returning to this project in Semester 2, the top priority was creating a larger interface and realise the vision of making a musical quilt. On August 3, 24 rectangular fabric placemats were uncovered on a shopping trip to find more fabrics at charity shops. The uneven sizing between each rectangular piece made me think that they were crafted individually and homemade. The human hand and craft were an important process I wanted to highlight in this project and thus, I created my patchwork quilt with these found fabrics.

Due to the handmade nature of the patches and subsequent quilt, the panels ranged in size from between 35-40cm. With a completed quilt, I moved to on the circuit layer underneath. Reaching for the main goal of creating a "musical quilt", I decided to embed the circuitry on the inside of the quilt so it was not visible to the user.

Using recycled aluminium cans, copper tape and duct tape, I created individual sensor pads that were a bit neater and more robust. I had also decided to create a duct tape covering over the Trill Craft (Figure 3.14) as the last prototype was experiencing some interference from the quilt when the Trill was exposed to the fabric and polyester wadding.

On 5 September, 2024, my artefact was installed during the New Interfaces in Musical

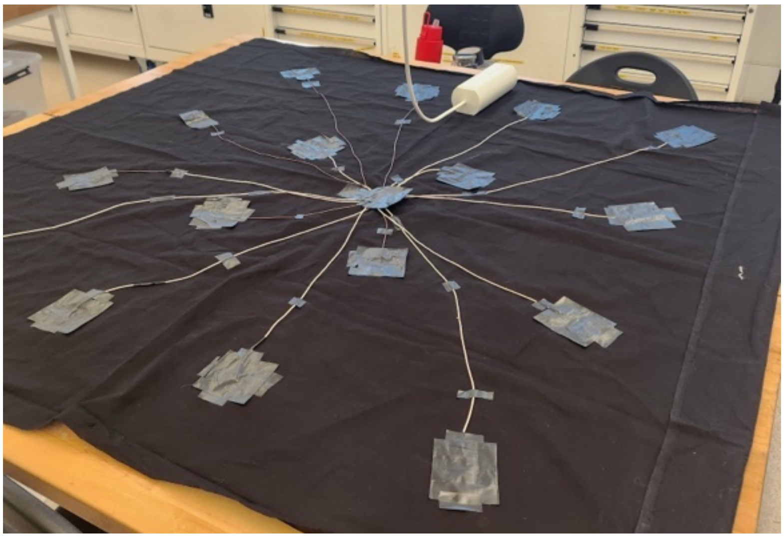


Figure 3.14: Sensor Circuitry (20 August 2024)

Expression (NIME) Conference Work in Progress session in Utrecht, Netherlands (Figure 3.15). Following this experience, I found that when I lay on the quilt, it caused interference on the Trill Craft. To remedy this, I made the decision to update the covering of the board with something more reliably non-conductive than duct tape. This ended up being a 3D printed PLA box designed to encase the Trill.

Another insight gleaned from NIME was that the small sensor squares left a lot of space on the quilt that did not cause an audio-visual output. Therefore, I expanded the sensors using layers of copper tape for better sensitivity (Figure 3.16).

3.1.3 Human-Machine Collaboration: AI Integration

As I was working on the larger quilt, my supervisor and I were also working on integrating an AI agent with the performance system. We made the decision to use Charles' Interactive Musical Prediction System (IMPSYpi) (Martin and Torresen, 2019) as the AI agent due to ease of use and accessibility to its creator for troubleshooting purposes. IMPSYpi is designed to engage in call-and-response improvisation between a performer and a trained machine learning model running a Raspberry Pi computer. IMPSYpi includes the ability to collect a dataset from the performer which can be transferred to a laptop to train new models.

As IMPSYpi ran on a Raspberry Pi, the decision was made to migrate from the Bela Mini to the Bela board to make use of the Ethernet port that would allow IMPSYpi to communicate with the Pd patch. From here, a Wi-Fi router was used to connect the Bela and Raspberry Pi via Ethernet. As there was no size 16 array trained model, I spent 2 30-minute sessions to gather data using my interface. Collecting data for the model involved pressing, stepping, rolling, and lying on the quilt (Figure 3.17). The

Figure 3.15: NIME Work in Progress Installation (5 September 2024)

Figure 3.16: Expanded copper tape pads (16 September 2024)

Figure 3.17: Gathering size 16 array of training data for IMPSYpi (25 August 2024)

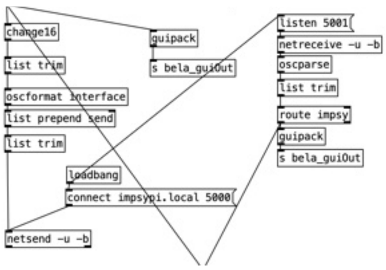


Figure 3.18: Networking functions in _main.pd

model was trained on this data using IMPSYpi's training command on a MacBook Pro computer with an Apple M2 processor.

The Pd patch had to be updated to handle networking and interfacing with the Raspberry Pi. Networking was done with the Pd 'netsend' and 'netreceive' UDP functions (Figure 3.18).

Due to the call and response configuration of IMPSYpi, where it would only answer when there was no input from the human agent, we had to implement logic to only send messages when there was change detected from the fabric interface. This was done by using the Pd 'change' object that only triggers when a change in value has been detected. This had to be abstracted to change16.pd which packs the 16 values when at least one change is detected (Figure 3.19).

Figure 3.20 outlines the main sections of the Pd patch: the organisation of the Trill Craft data, the network interfacing with the Raspberry Pi, GUI output, and sonic output.

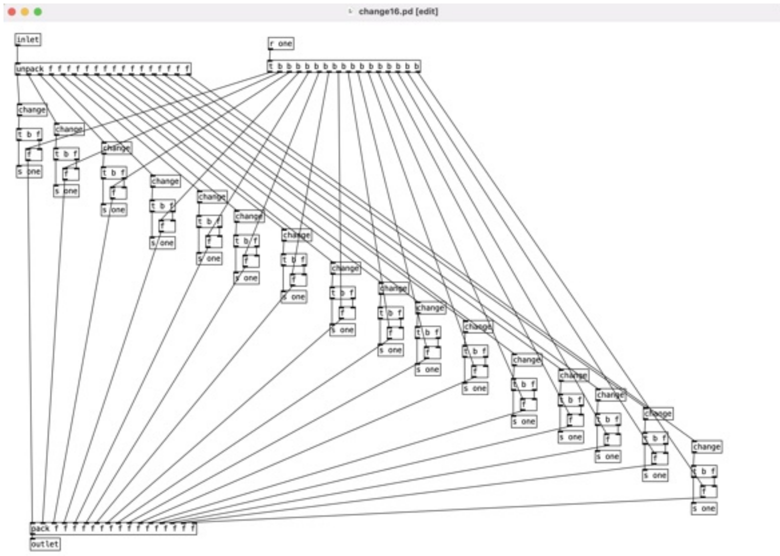


Figure 3.19: change16.pd abstraction

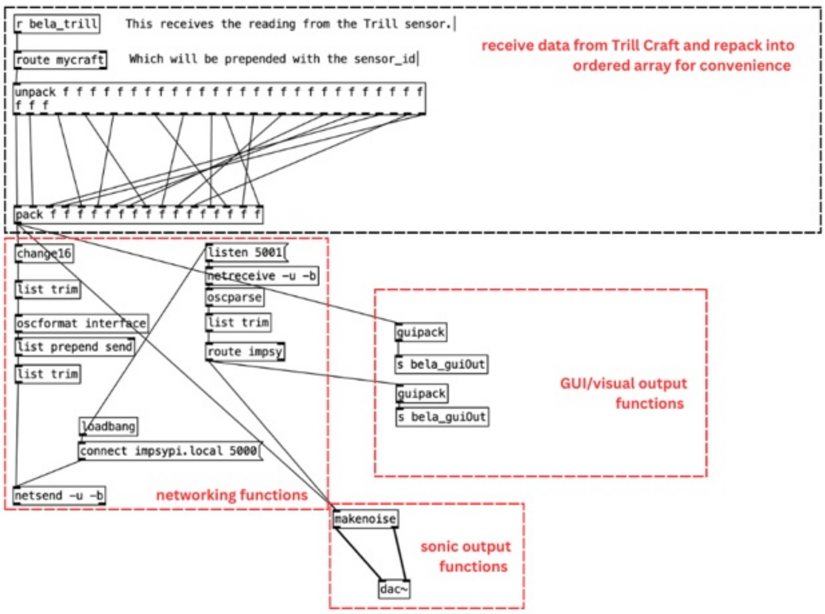


Figure 3.20: _main.pd patch—functional overview

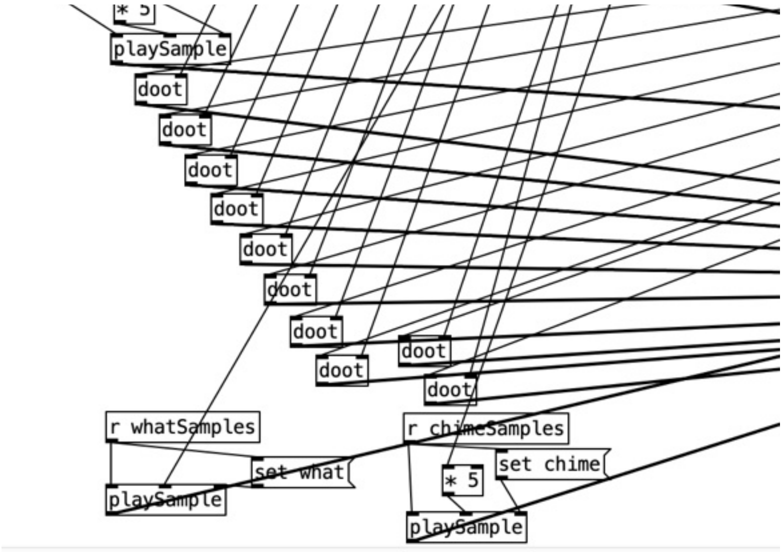


Figure 3.21: makenoise.pd patch—additional sample playback

On 27 August, 2024, a sigh of joy and relief permeated through the ANU Hanna Neumann building as a textile based musical performance system that integrates both human and machine input was born.

3.2 *Touching Wires*—4A Lab

In March, I had come across an application for exhibitions that "prioritises research and art grounded in experimentation, technology, and change" as a part of the 4A Lab emerging artist initiative with the 4A Centre for Contemporary Asian Art in Sydney. I compiled an application pitching the concept I had drawn up in March (Figure 3.2) and forgot about it until a month later when I received a rejection.

In May, I received a phone call notifying me that their October artist had pulled out and that I was on the reserve list for the October slot. Regardless of how this project progressed and ended, I now needed an artefact suitable for installation in a gallery setting.

After completing my user studies in September, I decided to make some changes to the sounds to create a more atmospheric soundscape—replacing two sine tone oscillators with samples (Figure 3.21). This allowed further diversity in the sounds made from both human and machine input (Sample video can be found in appendix B).

Recycled wooden palettes found dumped outside a store in Fyshwick, ACT, were used as the base of the installation. *Touching Wires* was now an interactive soundscape installation (Figure 3.22) where visitors could use the quilt to co-create with the machine (IMPSYpi).

Figure 3.22: *Touching Wires* installation view - 4A Centre for Contemporary Asian Art, Sydney/Eora

Chapter 4

Evaluations & Results

This chapter tracks the findings and analysis of data gathered throughout this project. The results include data on tactility, musical co-creation, and human-AI interaction. Sections 4.1, 4.2, and 4.4 capture the autoethnographical data from the researcher's personal artistic practice and reflections in designing, rehearsing, and performing with the interface. Section 4.3 details the process and results of data gathered from user studies conducted in September/October 2024.

4.1 Making, Rehearsing, & Performing with a Musical Tablecloth

As discussed in Chapter 3, the process of creating *Touching Wires* was iterative and decisions were made based on considered reflection. The initial vision of a tabletop interface (Figure 3.2) allowed for an embodied interaction but I had wondered whether I was simply "un-digitalising" a touchscreen. When I had started exploring textiles as an interface medium, I became obsessed with the concept of softness, and the juxtaposition it offered to traditional computing interfaces. These devices that have entered our most intimate spaces are inherently hard and solid, the next iteration trying to be more indestructible than the last. Moments where my phone has fallen onto my face in bed came to mind—why did we make rocks think? and why did we invite them into every moment of our lives?

When shopping for materials, I was reminded of the deep sentimentality offered by discarded textiles. With the intention of creating a patchwork quilt to layer on top of the tablecloth (Figure 3.4), I browsed for different fabrics I could collect and was overwhelmed by the abandoned nostalgia. A pillowcase with dinosaurs and the name 'Tyler' handwritten; a preschool class tea towel featuring drawings from each student; all items so deeply personal, and deserted in the corner of a charity shop bin. Reflecting

Figure 4.1: Message to close friends sent after buying fabrics for patchwork (28 March, 2024)

on the experiences these fabrics may have had—a pillowcase perhaps for school, a tea towel with designs drawn by a child and their guardian.

After cutting them into squares in preparation for patching, I was ironing the seams and the musty scent of the fabric steamed upward. This smell further compounded the sombre nostalgia and immersive embodied experience of textiles. After compiling a few patches, I had decided that the visual incoherency of the multiple squares did not provide enough intrigue to warrant covering the checks and roses on the tablecloth.

Initially when constructing the tablecloth, I had used one layer of wadding. However observing the quick changes in the sensor values, I decided to add a thicker layer of wadding to provide smoother control of the capacitive sensor. This allowed my hands to have a more diverse range of action when interacting.

My supervisor encouraged me to participate in a performance at the ANU School of Music on the 30 May, 2024. This performance would be a series of improvised musical acts featuring "Andromeda is Coming" (Charles Martin & Alec Hunter), Yichen Wang, and myself (the full concert video is linked in Appendix B). When rehearsing for this performance, I found that the springy surface encouraged more controlled and slower movements. It was rather comforting being able to rest with lower bass-like sounds engulfing my body as I lay my body down on the pillow-like instrument. As someone who is irritated by loud noises, I found the resonance of the low-frequency tones comforting and soothing in this instance.

The size of the interface (85x85cm) only allowed for upper body interaction (i.e hands,

(a) Hand-led movements (b) Head-led movements

Figure 4.2: Individual rehearsal session - 28 May, 2024

arms, head). I found myself working with two varieties of movement: hand-led and head-led. The body part leading would determine how the rest of my body would move and follow. For example, Figure 4.2a illustrates the leaning of my body after my hands had decided which sensors they wanted to activate. On the other hand, Figure 4.2b details a head-led movement where I decided to kneel my forehead on the interface, activating it with my head. From here, my hands curved around my head, removing themselves from the sensors they were activating.

The movements and sounds were reminiscent of intimate and meditative rituals, further highlighting the soft interaction with computer systems made possible through textile interfaces.

4.1.1 Solo Performance at ANU School of Music

The *Andromeda is Coming and Artificial Friends* concert at ANU School of Music (30 May 2024) was documented by two sources—Charles Martin's audiovisual live-stream, and a member of ANU College of Engineering, Computing, and Cybernetics (CECC) marketing team documenting video and photography.

For this performance, we had configured the stage to accommodate for all systems being presented (Figure 4.3). *Touching Wires* was placed in the middle of the stage to make the view of the floor-based interface accessible to audience members. In preparation for this performance instance, I had powered the Bela locally via USB on my laptop, and therefore needed to extend the wires connecting the Trill Craft within the cloth, and the Bela board to account for difficulties with the positioning of the interface and power supplies for my laptop. Also, due to grounding issues that would sometimes randomly spike the sensors, I had used pieces of cardboard and paper to raise the blanket off the

Figure 4.3: *Andromeda is Coming and Artificial Friends*, ANU School of Music (30 May, 2024)

ground to protect the circuitry from interference.

During this performance, a webcam was also mounted above the tablecloth to project a view of the interaction for those who did not have direct view of the stage floor. There were issues with the use of the webcam as the Bela was responsible for running the GUI and related functions. For security reasons, my browser did not allow the Bela access to the webcam connected to my laptop. To fix this I had to whitelist the Bela address requesting camera permissions.

My laptop screen was placed beside me for convenience and access but I had continuously referred to it for visual reassurance that my actions were effective. There were moments of silence in this performance when I had overwhelmed the audio buffer with too much sample processing and it would crackle and mute itself. Choosing to ignore it and go on with a movement improvisation, I found that the Bela self-corrected and began playing sounds as if nothing was wrong. When reflecting on these moments with my supervisor and colleagues, it seems that it was not too noticeable from an outside observer, as they were unfamiliar with the system's expected behaviours.

For this performance, I was allocated 8-minutes to improvise movements and sounds. Initially daunted by the length, I had decided on a structure of starting slow and focusing on the simple sine tones (~2 minutes), progressing towards the sampled sounds (~5 minutes), before descending back towards the sine tones to finish off (~1 minute). This

Figure 4.4: *Andromeda is Coming and Artificial Friends*, ANU School of Music (30 May, 2024)

plan was quickly abandoned when I started performing as I found the sine tones to be a bit too uninteresting to meaningfully fill 2-minutes of interaction. Moving toward the sensors controlling sample playback, I realised that the way the pressure of my movement affected the texture of the sound was interesting to explore further.

I extended my legs (Figure 4.4) in an attempt to engage more of my body however, found that as it did not actively participate in the system of soundmaking, it did not enhance or add to the experience. When reviewing my movements, I engaged in a lot more hand-led movements as it provided more control over the sounds. I discovered a rocking motion that allowed me to smoothly transition between playback speeds. Having the system playback on loud, theatre speakers created an engulfing atmosphere and made me much more aware of how my body was affecting the sounds. This consciousness made me less inclined to use head-led movements as they were less controlled, and more physically performative than sonically.

As the next act came to set up on stage to signal the end of my 8-minute improvisation, my first thought was that it felt much shorter than anticipated. Reviewing the footage[1], that moment occurs almost exactly 8 minutes after I started my interaction. Being fully immersed in the embodied experience distracted me from the timing of the performance.

In an article responding to the concert, the ANU CECC marketing team wrote:

> "*The human/computer duet unspooled a nebulous soundscape that felt and sounded like a scene from a movie, a guarded venture into a digital underworld where dissonant sounds — somewhere between whale song and Mechagodzilla — waited in ambush. The lightest touch of her hand would cause the roaring behemoth to run amok. Then, she'd touch the quilt in another place, and the beast would be corralled momentarily in a new envisaging of call and response, from human to machine and back again.*"[2]

[1] https://www.youtube.com/clip/Ugkxdk8SlH_d_7NuxCUK51-WrlpU18cVV1T_

[2] https://comp.anu.edu.au/news/2024/07/05/what-s-that-sound-a-duet-of-humans-and-ai-in-concert/

Figure 4.5: Kambri gallery demo (31 May 2024)

This suggests that the most impactful aspect of this performance was the exploration and display of the causal relationship between the textile interface and the soundscape.

4.1.2 Kambri Gallery Demo Recording

At the suggestion of my supervisor, I had organised for a documentation session of my progress at the end of Semester 1. This would take place at the Kambri gallery (ANU campus) on 31 May, 2024.

I had taken video of the setup and improvised movement with a camera, and recorded the sound output on an audio recorder placed next to the speaker. Insights gathered from this experience were a good point of contrast from the night before as the set up provided a vastly different experience. Having to set up the entire system myself – including speakers and projector – I found that my energy and mood were really influencing the way I engaged and the enjoyment I got out of the experiences.

The lighting in the gallery did not provide an adequate environment for the visualisations with the webcam feed to make meaningful impact as the blobs were visible, but did not have enough contrast against the changing light background. I had also forgotten to bring materials with me to shield the bottom of the tablecloth and was therefore required to reset the Bela multiple times. Additionally, due to the spaciousness of the room the speakers were unable to dominate the space.

These compounded issues obstructed a mindful interaction with the system, and thus I was unable to completely engage. This highlights the necessity of an audiovisual presence of the system in enhancing a mindful atmosphere for embodied interaction.

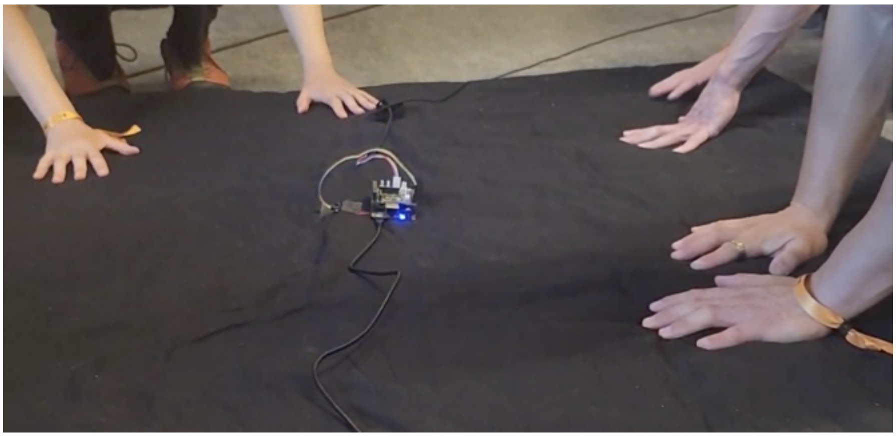


Figure 4.6: NIME workshop (2 September 2024)

4.2 Making it Bigger & Showing it to People

As discussed in Section 3.1.2, the priority returning to this project in Semester 2 was creating a larger interface. Upon shopping for suitable fabrics, I had uncovered several homemade placemats made from a material that looked and felt like Thai silk. Feeling a serendipitous moment tying in the handmade quality with my own intentions of centring handicraft, I made the purchase and created the quilt. This larger interface was presented at the 2024 International Conference on New Interfaces for Musical Expression (NIME) as a part of our workshop exploring embodied interaction[3] and as a work in progress demo[4].

After travelling halfway across the world to the Netherlands stuffed in my backpack, the quilt interface and Bela were not powering on. My supervisor noted that this was potentially due to the circuitry shorting somewhere. Upon further investigation, we found that a stray thread had been caught between the sensors of the Trill Craft. Adjusting this fixed the issue however, prompted the presentation of the interface at the NIME workshop to be upside down as to prevent any unnecessary interference for the Trill board.

The audio from the Bela was plugged into a speaker system that was shared with a different instrument, therefore there was some interference with the audio experience. The visualisation was hidden out of view from workshop participants as I had not calibrated the spacing and sizes of the blobs to fit with the sensitivity of the new quilt. As the audio was hard to hear, there were times were I had to step in and explain to people what was being actuated when people were touching and interacting. When unable to identify the sonic changes, I found people were searching for the tactile feedback by feeling the aluminium sensors that were more prominent as the quilt was upside down.

[3] https://www.nime2024.org/programDetails.php?id=431
[4] https://www.nime2024.org/programDetails.php?id=1507

Figure 4.7: NIME work in progress demo (5 September 2024)

When displaying it at the conference's work in progress demo 4.7, the quilt was on a raised stage at about knees' height. This height made me think of a bed and made it quite easy to lie down on. However, when I lay on the centre of the quilt, the sensors would jump and freeze at a peaked value, becoming unresponsive. As discussed, I had to then find ways of shielding the Trill Craft (Section 3.1.2), but at each time I reset the Bela, I felt a sense of servitude towards the system. Now that it was mature enough for external audiences, I had to consider the unexpected choices users may have when using the system and make the design robust enough for uses beyond my own practice.

While I found it easier to lie down with the quilt on a riser, the height made it challenging to engage my whole body since I had to step up onto the stage first. Thus, this presentation restricted the embodied experience that was able to be delivered by *Touching Wires*.

4.3 Showing it to Participants

Inviting participants to interact with the system in a controlled and observed environment provides us with data that helps understand the potential impact of this research beyond ones' personal artistic practice. Driven by the research questions, the following user study presented participants with the AI integrated version of the system (discussed in Section 3.1.3). A total of 12 individual user study sessions were conducted between 19 - 23 September, 2024. The ethical aspects of this study were approved by the ANU Human Research Ethics Committee (Protocol 2024/0995). For documentation submitted in the ethics application, please refer to Appendix A.

Figure 4.8: User study recruitment poster

4.3.1 Recruitment

Recruitment for the study began on 11 September, 2024 via my personal social media channels. Public Instagram posts were made with an image of the recruitment poster (Figure 4.8) and a link to expression of interest form from my art portfolio with a following primarily made up of Canberra/Sydney based artists, ANU students, and miscellaneous Canberra-based individuals interested in local creative practices.

After receiving their expression of interest, I sent out the Participant Information Sheet (Appendix A) and instructions for participants to confirm their availability. Participants were given a general overview of the project, expectations of their participation, risks, limitations, as well as the data collection, handling, and storage processes. Between 18 - 22 September, 12 participants confirmed their participation in the user study sessions.

4.3.2 User Study Specifications

This study presented the system to participants in room 2.32 within the Hanna Neumann Building on ANU campus. The system setup (Figure 4.9) included speakers placed on either side of the quilt for audio playback, and the visualisation displayed on a laptop screen placed to the side. A go-pro was set up to film each session and additional audio was captured during the semi-structured interview.

Participants were instructed to "interact with the quilt however you like", with a note that there are wires attached so lifting the interface was discouraged. I provided a brief

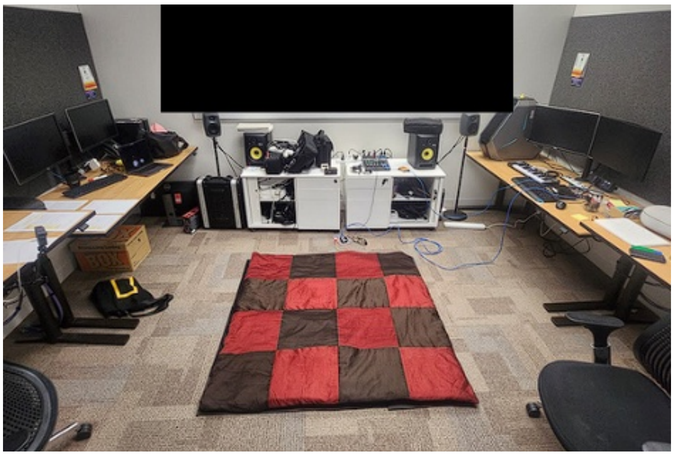


Figure 4.9: User study set up (19-23 September, 2024)

verbal overview of the system and each participant was given 8 minutes to create a musical interaction/performance with the AI agent. They were instructed that they could end the performance whenever they saw fit either before, at, or after I gave them a verbal 8-minute indication. After the performance, a semi-structured interview would take place with the following prompt questions:

1. Can you describe your initial impressions the musical quilt?
2. How did your impressions of the quilt evolve as over the session today?
3. Can you describe your thoughts on the AI component in this system?
4. What roles did you think that the AI component had in your performance?
5. How do you feel that your performance evolved?
6. Did you feel like you were developing a relationship or collaboration with the AI component in the system? Did you feel trust (or mistrust) when interacting with it?
7. Could you talk about aspects of this experience that you found enjoyable?
8. Could you talk about aspects this experience that were confusing or frustrating?

These questions helped guide each interview to remain within the scope of the research questions. Depending on the direction of the interview, I had improvised supplemental questions to clarify statements made by participants.

4.3.3 User Study Findings

Transcription of interview audio was completed using the Sindre Sorhus' Aiko software on a Macbook laptop on 25 September, 2024. Aiko uses OpenAI's Whisper locally on

Figure 4.10: Gathered data organised on Miro board

the device. Quotes were then taken from each participant's transcript, and organised as individual notes on a Miro board for further analysis.

Braun and Clarke (2021) define thematic analysis as the method for developing, analysing and interpreting patterns across a qualitative dataset. Their proposed approach of reflexive thematic analysis incorporates critical reflection on the part of the researcher through the process of data familiarisation, coding, and theming. Researcher subjectivity is leveraged to better situate and conceptualise knowledge that is interpreted from the data and its themes. We use thematic analysis in this project to bridge and interpret user perspectives, from both creative and non-creative backgrounds, to articulate perceptions of AI in human-AI co-creation. Thus, we are able to better define the roles of AI in human-AI co-creation.

Each colour denotes a different participant, and we will refer to them as P1, P2, P3, and so on. The original organisation was based on the structure given by the interviews. These notes were then coded to identify the key takeaway from the quote.

Initial findings validated that the system successfully met the specifications outlined in Section 1.2.

- **be large**: Multiple participants used different parts of their bodies to interact with the system within their co-creation time. This included positioning themselves off the quilt and interacting with their hands (Figure 4.11a), laying down with their entire bodies (Figure 4.11b), stepping with their feet (Figure 4.11c), or positioning themselves on the quilt and actuating with their hands (Figure 4.11d).
- **be tactile**: Participants overwhelmingly used hand-led movements that centred the tactile experience of creating sounds. P6 cited that their initial interaction with the quilt was dictated by its materiality where "it looked a little bit textural but not too bumpy, so I was excited to touch it". This suggests that the quilt was

successfully perceived as a tactile interface.

- **be fun**: Most participants noted that it was an enjoyable experience getting to play with a novel interface and create sounds, with P9 describing the system as "a fun little map and it felt like I was just a kid playing and exploring".
- **incorporate both machine and human input**: When questioned about their thoughts on the AI component of the system, many participants voiced that they "didn't really notice it" (P3) or "wasn't aware of it much" (P6). P10 summarised that their experience was a process of "learning what the relationship [with the AI] is". Therefore, while all participants were made aware of the machine input and presence before beginning the user study, their experiences within the session highlight that the AI interaction was not a formative part of engaging with the system.

Through further analysis of the data gathered and their associated codes, we find the following three themes threading our user study sessions together.

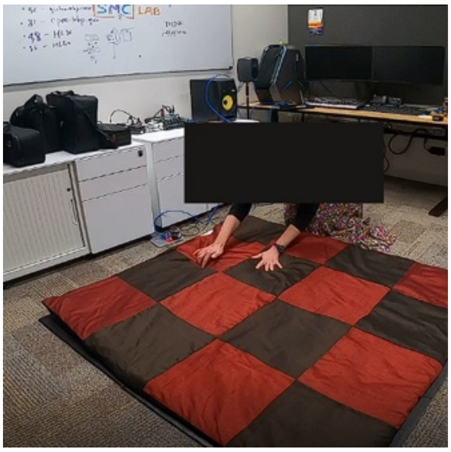
Choice and agency are informed by expectations

Our expectations influence the choices we make when constructing experiences. This user study uncovered the entangled nature of participants' expectations and assumptions in shaping their actions and experiences.

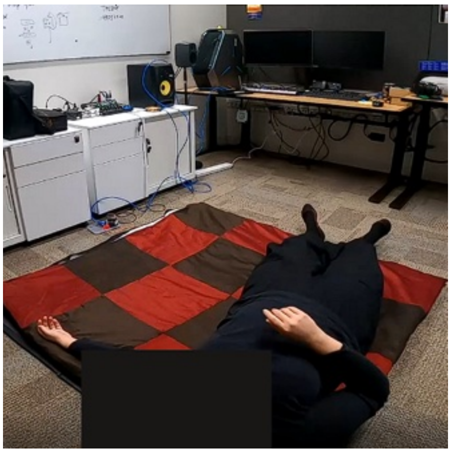
Participants were informed of the three components of the system before their co-creation session which would have immediately triggered associations or expectations of their interaction with a quilt, a digital instrument, and an AI agent. P8 stated that "*I think over the session I was mainly trying to understand if/how my interactions with it kind of affected the audio*" highlighting their intention on trying to find a causal relationship between the quilt and the DMI. As the session progressed, they were "*trying to look at the areas where I could see more wear on the quilts*" to infer on what actions may have been popular for previous users of the interface. This indicates that their expectations about usage and wear motivated them to examine the physical signs left on the quilt.

P9 noted "*the mat itself doesn't look immediately like you're doing something by pressing on it, because I'm used to my doona not doing anything when I touch it*" highlighting the presence of expectations guiding their actions. P9 goes on to say that "*it was that kind of [audiovisual] feedback that confirmed that what I was doing had an impact*", affirming how when they were unsure of what to expect, their actions were guided by experimentation to find causal relationships between their actions and the system response.

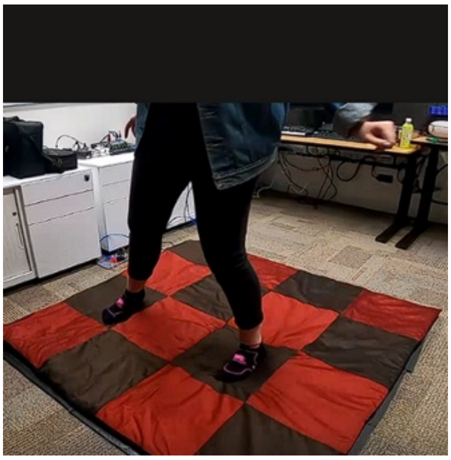
Associations and conclusions about expectations were also conveyed through the physical design of the quilt. P7 described the "*patterns like hopscotch ... like moving a knight across a chessboard*" that P5 "*was perceiving as an automatic structure for me to play with*". Both expectations were derived from associations with the checkerboard pattern and encouraged both participants to explore for a period on their feet with movements that actuated one sensor at a time. Additionally, P5 attributed their desire to lie down



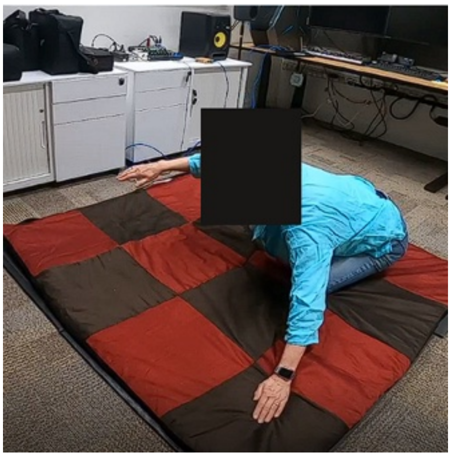
(a) Hand-led movements



(b) Body-led movements



(c) Feet-led movements



(d) Hand-led movements

Figure 4.11: Participants in user study sessions (19 - 23 September, 2024)

and roll around to "*I guess I was trying to connect to this idea of it's a quilt, right? Like, I'm not at home doing this*", highlighting that an association with textiles guided their actions.

Furthermore, P12 described a rigidity in the quilt as "*the colours ... it made me feel like it was hard ... my initial reaction was 'I'm going to play it like a drum' and then I realised, no, it's not quite doing what I anticipated ...so I thought I'll blow it, just have some fun with it*". This prompted P12 to attempt all sorts of movements for interacting. First, as they described, they started with hand-led movements like drumming, chopping, patting, then they began incorporating their knees and crawled over the interface before finally deciding to lie, roll, and spin around the quilt. The progression towards careless action points towards their desire to "*just have some fun with it*", ultimately driven by a misalignment of expectation.

Expectations of AI were also prevalent in the participants actions, and subsequent perceptions of their relationship with the AI agent. P12 said: "*I think any experience I've had with AI at this point, I ask a question, it gives me an answer, or there's a reciprocity, but it's limited. And so I thought with this, if I touch it, it will give me an instant response. But it didn't ... I just had to do my own thing, and find my own rhythm, and enjoy what I was doing rather than try and communicate*". Therefore, their previous experiences with AI entities provided a base expectation of reciprocity, and when that expectation was not met, P12 expressed an altered goal in the interaction, and thus altered actions.

Many other participants expressed a misalignment of expected behaviours from the AI. P7 stated "*I didn't feel like we were working together ... I felt really energised and involved when I was touching and then I just felt like when I wasn't ... [the AI's output] wasn't an equal sharing*" alluding to the expectation of equal participation from the AI agent. Similarly, P5 stated that "*I would like it to be interacting **with** me", and likewise for P3 "the AI didn't learn as quickly or visibly as I expected it to ... I didn't feel like I was interacting with anyone*" thus, describing a disappointment as the AI did not participate as anticipated.

The different processes of exploration and expressions of surprise from participants highlights that expectations drive our expectations and considerations when exploring new environments and systems.

Different starting points to access multi-sensory embodiment

Multi-sensory experiences enhance our connection and presence in embodied interactions however, require one access sense to inform the actions in constructing the multi-sensory experience. The relationship between our senses in forming our understanding with new interfaces and systems was expressed by multiple participants.

Many participants expressed the desire to single out the system one sense at a time. For example, P6 highlighted that they were "*focused on the actual interaction and my* *involvement in where those sounds were coming from. So I think it might've blocked out what else was going on.*" when questioned about why they were not referring to the visualisation. Similarly, P3 stated "*it was making sounds that I don't view as a contemporary music instrument ... I didn't take in the visualiser at all*", further outlining the desire to focus on one sense at a time. Furthermore, P4 commented that "*it was harder to get the cause and effect until I figured out if I just hold something [the AI] stops*", outlining that being overwhelmed with a sensory experience may be detrimental to an immersive experience. Thus, we can posit that the sensory comfort of a user is integral to their engagement and participation with the system. This also highlights the importance of focus and understanding through one sense, which facilitates further exploration, study, and building up of the multi-sensory experience.

When exploring the tactile experience, P5 remarked that "*I still felt like my feet were dominating the sound and then I laid down and I quite liked the lay down. ... your hands have got more control*". This highlights the multi-sensory experience wherein the embodied reaction is determined by both tactile and sonic feedback. The audio reaction informs the tactile experience. Likewise, P7 "*noticed that if I pressed with my two fingers, there was a sound, but then I pressed with four. And then it changed it, and so then I wanted to, like, knead out to a point. ... I would never have generally considered my physical involvement in the making of a sound, and there's, like, a reciprocal pattern there*" explicitly describing the relation between sound and tactility in forming their embodied understanding.

From a contrasting perspective, P11 noted that "*the size and having to move around a lot is a bit weird ... it is a little bit tedious and if you want to move from like there to there you kind of have to either reach really far or walk around*". P11 was the only participant to conclude their co-creation session before the 8-minute indication. This emphasises how the scale of the interface impacts the understanding of and embodied interaction with the system. Furthermore, P11 "*kept looking at [the screen] to see what changed when I touched things ... just pattern recognition I guess*" reinforcing the multi-sensory reassurance for participants' to understand the novel system. Therefore, the visual insight into the system informed their agency in constructing their overall experience.

P12 remarked that "*I tried to listen to the sounds as I moved my body to it, and then in the end, I could hear, something would, I would discover a change, and I would try and pursue that change, but it didn't always do what I anticipated it to do, so in the end I just had to be spontaneous with it.*". Likewise, when discussing the sounds made by the AI, P9 felt that "*definitely felt like it was influencing me,*" when discussing the sounds made. This further highlights the multi-sensory experience informing the embodied interaction; with the tactile led by the audio.

The differing sensory start points, and process of exploration from these participants suggests that, all of our senses come together to inform our interactions and immersive embodied experiences.

Engagement, curiosity and embodied experience clarifies the unknown

Novelty and joy encouraged exploration, and we found that agency and confidence for humans to participate and investigate grew through active involvement which in turn clarified their roles in the co-creation. The participants in our study described the journey through their co-creation, and the emphasis on finding familiarity to further fuel confidence in their participation.

P1 described "*the surprise of not knowing what sounds at the start would be where and how they related to each other spatially*" had eventually led them "*to a point where I could sort of use it to compose with or like make music with*". This highlights the journey of exploration building confidence in the user. Conversely, P2 "had no idea what it was doing ... I still have absolutely no idea how it works", and as they did not explore with any movements other than stepping on each square, this highlights how that journey of exploration is important in forging understanding and clarifying roles within a co-creation context.

P6 commented that "*I think I became a lot more confident and relaxed towards the end of the process and when I knew that I wouldn't necessarily kind of hurt it or damage it, I became a lot more kind of comfortable and relaxed around it*" which reinforces the process of discovery and the agency associated being fundamental to building understanding of new systems.

The discussions around the AI unveiled that for many participants, the novel interface had distracted them from engaging with the AI and make full judgements. P5 expressed the desire for more time with the system as "*I felt like I just started exploring*", outlining the importance of familiarity in forming connections. Furthermore, P5 said that "*I wasn't expecting to see what looks like a quilt. I was expecting to see the tech. I was happy to see this ... I don't even understand AI ... so I guess it's like a participatory work where the AI and I are chilling out together*". As an artist with "*a sound practice,*" P5 emphasised the tendency to articulate the unknown in familiar terms, framing their co-creation as a participatory artwork. Active participation and generating personalised understanding allowed the participant to define their own role in the system.

Similarly, P12 thought that the AI "*was either mimicking me, mocking me, or taking me on a different road ... I just had to do my own thing, and find my own rhythm, and enjoy what I was doing rather than try and communicate*", outlining that the exploration of the system led to a clarified formulation of personal and active goals in participating with the interface.

Additionally, P6 mentioned that "*I didn't take too much notice of the AI component. I think I was primarily focused on my involvement with the pressure points and I wanted to either make music or make a sequence of sounds*" and "*I didn't [feel trust or mistrust] I wasn't aware of it that much.*", conveying the lack of intimacy preventing a formalised relationship. Therefore, fostering better exploration of these new environments through novelty can improve agency and clarity in human-AI relationships.

The sounds created by the machine-generated input provided many participants with an immediate entry of recognition to the system. P1 stated that the "*AI was reliable in a sense,*" and that "*knowing if I didn't know what to do, I could just wait and it could give me a nudge in the right direction ... and I could fall back on it*". Similarly, P9 felt "*it was cool having background noise to start me off*" however, "*I don't think that I put enough of a personality or like personhood onto it to be able to trust or distrust it. I know that what it is, is a program that knows how to use training to like evolve and make decisions*". Therefore highlighting that the response to the reliability is not necessarily one rooted in emotion or trust. P4 posits that this reliability could also be a hindrance—"*early on it was there and it was cool and it gave some background noise but it kind of stopped me from seeing the cause and effect of my actions*". This further highlights the importance of individual agency in forming their understanding of the system. Only through active participation can users clarify the intentions of their participation.

Human-AI co-creation systems that foster active participation from human are able to build confidence and agency to define their own intentions and roles in the interaction. Novelty and joy designed within the system empower users to investigate through their own choices.

4.4 Performing & Exhibiting

As introduced in Section 3.2, I had applied and been accepted to present my project in a solo exhibition at the 4A Lab in Sydney (Figure 4.12). The application proposed the earliest iteration (Figure 3.2) therefore I knew I would have to install *Touching Wires* for public interaction within a dedicated gallery space. A short demonstration of this installation is linked in Appendix B.

For the opening night of the exhibition, I decided to do an improvised movement with performance artist Isabelle Laxamana on the AI integrated iteration of *Touching Wires*. The 15-minute improvisation would be structured in three 5-minute segments: Sandy duet with IMPSYpi, two humans + machine trio, and Isabelle duet with IMPSYpi. This was motivated by my realisation that our intentions differed when interacting with the system. As the creator of the work, and having interacted with the project for 8 months, I had a deep familiarity and closeness that Isabelle did not. The day of the performance would be the first time Isabelle had seen and interacted with the quilt.

Prior to the performance, I was thrilled to explore with my whole body, however, found that the physical presence of another person discouraged me from exploring the other half of the quilt. During our only rehearsal, I did not use my lower body to interact at all, except to move around the edge of the installation. I was determined to try and involve my entire body more in the actual performance but once again found the physical space to be segregated. During the performance, I found myself engaging with stroking and pressing motions instigated by the larger surface area, as well as the fully embodied

Figure 4.12: *Touching Wires* at 4A Lab external view

experience brought about by the sample replay speed noticeably different depending on my actions.

Additionally, during the performance, Isabelle and I fell into a mirroring exercise, where we would mimic each others movements on opposite sides of the interface (the full performance video is linked in Appendix B). This mirroring made me focus on my human counterpart, ignoring IMPSYpi however, early on the Trill Craft may have shorted and the OSC messages were no longer sending. Thus, we were able to lay the quilt while IMPSYpi's inputs were also being played. I felt that this trio configuration added additional tension and connection between each participant, as it sonically and visually portrayed everyone's presence.

Within this exhibition, I had also created a textile work *Prompt Engineering (2024)* (Figure 4.14) which were poems printed on silk cloth. Each poem was generated in response to my asking—"*Can you write me a poem responding to the prompts: AI, diaspora, technology, touch?*". This process was born out of a desire to have a work complement *Touching Wires* in the exhibition, and a different reflection on my relationship with AI. I considered the idea around "prompt engineering", and the traces of labour when interfacing with generative AI. I invited five poets to contribute poems to be displayed alongside ChatGPT's response, but only two responded within the 3-month window I had dedicated to the work—a lengthy timeout period rarely given to computers. This process reminded me of the nuances in communicating with humans, but also the fact that I had practiced all my life to do so. I had very little practice in communicating with

Figure 4.13: *Touching Wires* at 4A Lab Opening Night Performance featuring IMPSYpi visualisation (10 October 2024)

AI models, and had consciously avoided ChatGPT in my work. Therefore, who was I to judge those advertising their prompt engineering skills?

Throughout the opening and exhibition, I found that I had assigned a sort of personhood to IMPSYpi, referring to it as 'her'. This assigned personality also informed my movements within the performance. During my solo part, the Bela had once again been overwhelmed with audio processing and gone silent. In this moment, I found myself kneeling my forehead to the quilt, as if to plead to the system to recover. When the installation was on, I also found myself patting the quilt in a soothing motion as I had found that if I actuated the sine tone oscillators while the Bela was overwhelmed with sample processing from the IMPSYpi input, it would recover. Over the 7 days the exhibition was open, I had 45 visitors come in and interact. This meant there was a lot of time where the installation and I sat alone. I found the new soundscape design and implementing more sample processing gave the work a dimensionality that encouraged a personality to be imposed onto the system.

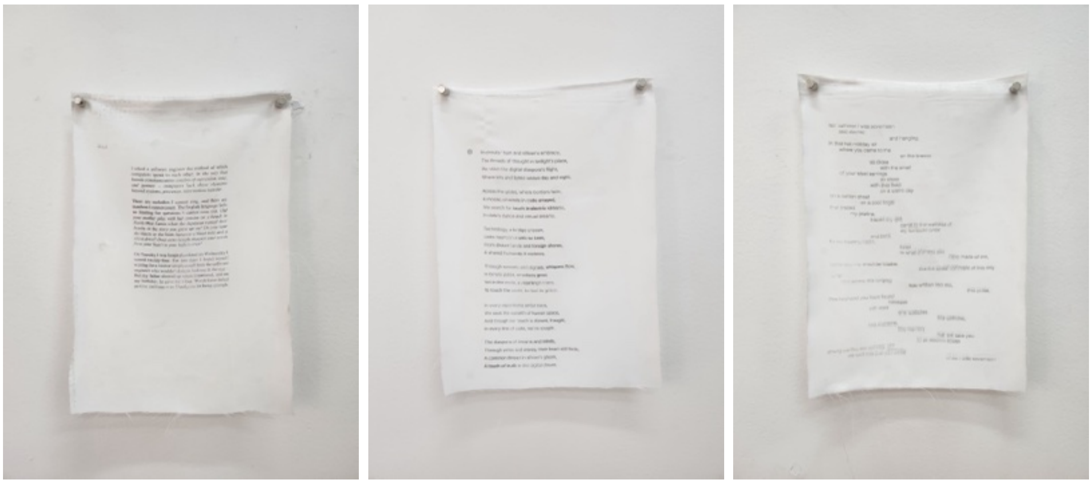


Figure 4.14: *Prompt Engineering* (2024), text on cloth
Words by:
Isabelle Laxamana, ChatGPT-4o Mini, and Junnade Ali

Chapter 5

Discussion

5.1 Addressing the Research Questions

Tactility forms an immediate and tangible connection to our environment, fundamentally shaping how we perceive and interact with the world around us. Thus, we must evaluate the role of tactility in forging human-AI interactions in order to better design frameworks for creating and using autonomous systems, particularly in creative practices. The following discussion outlines our findings within the context of our initial research questions.

5.1.1 What roles could tangible and embodied interfaces have in human-AI co-creation?

Tangible and embodied interfaces mediate meaningful interaction by inviting the user as an active participant with their own agency. Bringing tangible and embodied interfaces into human-AI interaction enable a physical connection to an otherwise abstract entity. Fostering personal connections allow us to demystify social apprehensions of AI to further enhance the potential to collaborate.

Co-creation requires a process-driven definition of creativity rather than output-led. Creativity must be framed as a skill to be developed and refined rather than an ethereal black-box power. This study showed that people more comfortable with creativity were more willing to explore and create. As creators of emerging technologies and forms of expression, we have the privilege to redefine creativity for mass audiences and encourage new experiences.

Creating enjoyable experiences encourages active engagement in participants and is therefore a powerful tool in providing education around AI systems. Joyful experiences encourage individual agency and promote a sense of ownership over the interaction. When users find pleasure in engaging with AI systems, they are more likely to explore and experiment, leading to a deeper understanding of the technology. This engagement not only enhances familiarity but also encourages users to take an active role in shaping their interactions. Furthermore, designing for joy can reduce apprehension associated with AI, allowing users to approach these technologies with curiosity rather than fear. This shift in mindset is crucial in fostering meaningful human-AI collaborations, as it enables individuals to view AI not only as tools but as partners in creative and problem-solving processes. Leveraging co-creation contexts allow users to feel empowered to experiment without the pressure of making "correct" decisions, therefore uncovering new potentials and ways of engaging with AI systems that may not have been initially envisioned by designers. This co-creative process benefits both users and designers, as it opens up channels for feedback and iterative improvement.

Weisz et al. (2024) propose key design principles for generative AI including designing for co-creation, trust and reliance, and imperfection. This project finds that designing to give users agency to craft their own evaluations and outcomes is imperative to forming positive experiences with new systems. Co-creation in human-AI systems should be defined by the process and interaction as that enables more productive outcomes.

5.1.2 What do textile interfaces enable in digital musical instruments?

Materials carry memories that can be activated through tactile sensations. As our lives become entangled with emerging technologies, users bring their own assumptions and expectations to interactions, therefore creating multi-sensory embodied experiences enable exploration where users can validate their actions through their multiple senses.

Textiles offer an intimacy rarely afforded by materials associated with computer technologies, despite their integration into our most private spaces. As evident in Section 4.3, expectations dictate our choices in constructing experiences with novel interfaces. Thus, being conscious of the expectations associated with material during the design process can harvest more critical interactions.

Ethical and moral issues in material production plague both textile and electronic production and manufacturing. Thus, investigating both in tandem can offer designers better frameworks towards ethical making. Increasing visibility of these issues with active practical engagement increases the potential for manufacturers to be held accountable for their questionable ethics. This study uncovered that actively reflecting on our connections with materials can enhance the making process by shaping the intention, and thus forming more ethical practices and outcomes. If we embed these ethics into the way we think about and create technology, we can make better frameworks for combating the ethical issues that exist within these spaces.

Considering materials also increases the accessibility of making. Harnessing universal associations with different materials can offer new avenues of expression, representation, and embodiment. Design should be centred on connecting users through their own stories and their own voices. Textiles offers an immediate access into peoples' lives, and thus a proximity to comfort. Our study finds that the actions when interacting with textiles are guided by softness, and curiosity is sparked when presented in a novel context.

"*If nothing else, fabrics as instruments should prompt a playful, fun interaction.*"

- Sophie Skach et al. (2024)

Design practices & technology

Using recycled textiles as a key motivator in practice also enabled a slower and more considered design practice. Amplifying makers and DIY electronics empowers communities of knowledge, therefore advocating for co-design theories within broader technology spaces.

Iterative design allowed this project to flourish and clarify its research intentions progressively. Taking practice-led research enabled immediate application and evaluation of current changes. Creating and designing with the people using these systems rather than for them enables better critical engagement with the solutions being made.

5.1.3 How can embodied human-AI interactions enable trust?

Tactility actively engages the body, deepening our understanding of embodied interactions. Additionally, touch bridges the experience of the body with the rest of the senses. Enhancing personal connections with AI through carefully designed interfaces has the potential to enable relational trust. Larger interfaces invite the entire body into the interaction as they are spatially captivating. Leveraging larger interfaces to mediate more diverse multi-sensory embodiment invite mindfulness and presence into the interaction.

Dourish defines embodiment as phenomena "*that by their very nature occur in real time and real space*", a definition that involves both the physical and the transcendent (Dourish, 2001). In this study, we capture definitions of embodiment as the interaction of all the engaged senses. Tactile engagement that is reinforced by the audiovisual fosters a sense of presence, where individuals become fully immersed in their experiences, transcending simple observation to engage in a dynamic relationship with their surroundings. No external participants explicitly used the term 'embodiment', but many described the relational interaction between their bodily actions and their sensory experiences.

Cohesion among the senses allow embodied experience to be truly immersive. When users are able to see, hear, and feel a change enacted, it creates a dialogue between their bodily experience and the world. Embodied dialogues foster active participation where users are not just passive recipients but dynamic contributors to the ongoing experience. This heightened engagement encourages emotional connection, deepening the interaction and allows users to forge more meaningful relationships within these spaces. When forging awareness of abstract entities like AI, creating systems for embodied dialogues cultivates further investigation in articulating human-machine relationships. Embodiment allows us to spark agency through movement and interpretation of our sensory experience, thus enabling active participation and building confidence to interact.

As users engage in collaborative activities, the integration of sensory inputs helps to dissolve barriers, allowing for fluid interactions that are both spontaneous and meaningful. In contexts of musical co-creation, embodiment adds an extra dimension of exploration for participants to explore and create. The output is then multi-dimensional, and offers a setting for creative collaboration from multiple perspectives.

Familiarity allows us to form relationships and trust with external systems. Understanding the autonomy and structures of AI systems can enhance human users' ability to navigate their complexities and make informed decisions. An understanding of the system allows humans to make formal judgements on their perception of the AI agent, thus forging a relationship between both actors. A close familiarity with the system encouraged me to actively seek the AI agent as a collaborator, eventually imparting personhood onto IMPSYpi. Building relationships takes time and effort, and Human-AI trust evolves over time (McNeese et al., 2021). As advocates of the systems we create, we must put in effort into creating circumstances and spaces for relationships to develop. Helping human counterparts understand the role of the AI in that interaction is imperative to fostering human-AI collaboration. A user study participant indicated that "*I don't think that I put enough of a personality or like personhood onto it to be able to trust or distrust it. I know that what it is, is a program that knows how to use training to like evolve and make decisions.*", emphasising that even though there is no personality associated, the understanding of the role of the AI fostered a productive interaction. Additionally, this suggests that there is an innate desire to impart a personality to determine trustworthiness. Noting that the definition of trust does not inherently require personhood—e.g. trusting that a machine will work in the way it is intended. Empowering individuals to explore and clearly define their roles in interactions fosters active participation in collaborative environments. The user study also suggests that humans desire the time, space, and autonomy to build their own relationships and understandings.

Forming tangible understanding to our personal contexts allow us to develop deeper familiarity, and thus more productive relationships with emerging technologies. Negotiating common experience using metaphor provides a way for us to apply our lived experience to understand new information and interaction with the world (Reed et al., 2023). As documented through user experiences, finding a personalised understanding of the situation allowed for deeper engagement in the overall system. Participants who were able to form an understanding of the system were able to successfully co-create and participate. Noting that it was not necessary for this understanding to accurately reflect reality, as long as it resonated with their perceptions.

Human-computer interaction does not exist in a vacuum, and so system designers must consider the complexities and nuances that humans bring to these interactions. Entanglement theories offer frameworks to better articulate how individual experiences can inform HCI (Frauenberger, 2019). Timothy Morton argues that the interconnectedness of our lives and our technologies means we are responsible for our creations, and specifically for AI beings as "we can't tell whether the AI beings are alive or sentient" (Morton, 2010). Users' assumptions and perceptions of AI influence their interactions, a factor beyond the designer's control. Therefore, it is essential to foster adaptable associations within the technological structures we create. Recognising that expectations shape choices highlights the agency embedded in a broader context. In designing interfaces for human-AI interaction, we must consider how users perceive the structures of these experiences and their impact on the relationship between humans and machines.

Researchers have argued for the anthropomorphism of AI in hopes of increasing trust and interpersonal connections with autonomous chatbots and systems. However, Nicholas Barrow posits that this "limits our understanding of AI to *human terms*" (Barrow, 2024). Likewise, McCormack et al. questions "why dismiss outright that a machine and a human might share experiences that result in something meaningful and worth communicating? ... what could possibly be the defining characteristics of an autonomous computer artist" (2014). Bringing human expectations to AI means humans expect a humane interaction. Rather, we need to design human-AI interactions that create new understandings of these new technologies. Thus, the tangible representations of AI must fit the individual contexts.

5.2 Limitations

This project examined human-AI musical co-creation where human input occurs via tactile touch of a quilt, and machine input is generated as an array of 16 float numbers. As IMSPYpi cannot communicate in a way that can semantically express its perspectives, we are unable to capture the other perspective in this relationship.

There were also technical limitations unable to be investigated and considered within the scope of this project. As mentioned previously, the Bela was, at times, overwhelmed with audio processing leading to audio glitches. This remains unresolved within this project.

During the installation (Section 4.4), the Bela remained on for a few hours continuously without any human input and suddenly refused to detect the Trill Craft. This was resolved by switching the power off and on again, and I was unable to reproduce the issue. However, this seems to be a physical limitation of the Bela that may be worth future exploration.

Chapter 6

Conclusion

This thesis describes the processes of creating and evaluating a textile human-AI musical co-creation system over the course of 2024. Through this system, we articulate the roles and applications of tangible and embodied interfaces in human-AI interaction.

This chapter provides an overview of our project outcomes and threads the links between our findings to answer the research questions. These findings also inform future directions that this body of work can evolve toward.

6.1 Evaluating the Project Outcomes

Tangibly, the artefact created through this project is a textile musical interface that can be used independently for performance. This quilt interface controls a digital musical instrument that also accepts machine generated input. Together, the system supports human-machine musical co-creation (Figure 6.1).

This system presents an application of embedded computing within computer music systems on the Bela audio platform that takes in human input via a capacitive quilt interface, and machine input from IMPSY—an interactive musical prediction system (Martin and Torresen, 2019) that uses a mixture-density recurrent neural network to engage the human performer in call-and-response interaction. This system has been presented as both an instrument for musical performance, as well as an installation for public interaction.

Through this artefact, we have investigated the role of tactility in human-AI musical co-creation, and explored embodiment as a way of forming connections with emerging technologies. Reflections on performances and presentations of the system enabled clearer understanding on what a personal relationship with AI systems can create. Presenting this system to external participants and colleagues allowed us to gather data

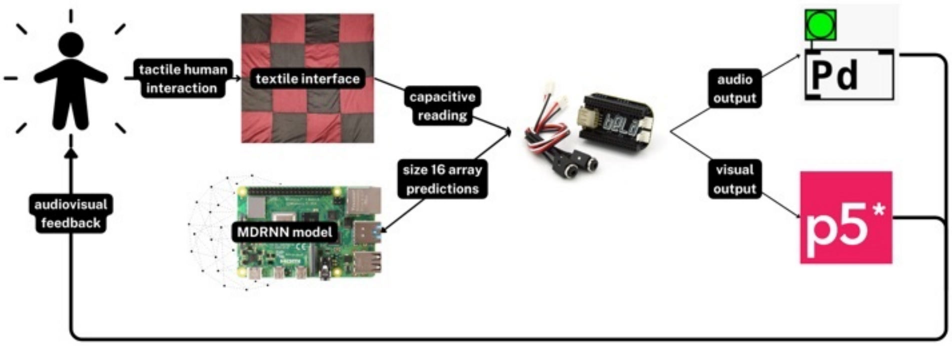


Figure 6.1: *Touching Wires* system design diagram

from multiple perspectives to be compared. Additionally, user study data enabled a triangulation and validation process to occur in the practice-led research.

We have found that tangible and embodied interfaces invite users to be an active participant in human-AI co-creation, and familiarity and embodiment to be key in connecting users to novel systems. The underexplored textile medium has the potential to bring fun, novelty, and deeply personal associations into AI-enhanced digital musical instruments. Leveraging materiality in design processes invites immediate access into users' awareness and understanding. Multi-sensory embodiment offered by tangible and embodied interfaces provide users with the agency to choose how to participate and collaborate. This agency encourages trust as humans are able to form deeper familiarisation with AI systems.

6.2 Future Work

6.2.1 Articulating the Role of AI in Creative Co-Creation

Deconstructing and defining the role of the machine in human-AI creative co-creation equips us with the tools to better shape the artist's relationship with the growing autonomy in their technologies. As autonomous systems are being scrutinised for their systemic racial and gendered biases, interrogating the creative applications and outputs of these systems will provide further evidence to guide the development of these systems.

This project uncovered the existing mysticism surrounding AI in creative practices, as well as the potential for collaborative human-AI practices when the system (in our case IMPSYpi) has been created by artists for artists. A more cohesive understanding on the roles of creative practitioners encourages more ethical and considered forms of creative expression through engaging with the voice of artists. This can be investigated by further work with exploring applications of AI in creative practices through the work of creatives within this interdisciplinary practice. On the other side of this, better articulating roles help technology makers better shape their guidelines and principles when creating systems for creative purposes.

6.2.2 Textiles in Computing

This project has highlighted the vast potential of textiles in creating embodied experiences for diverse means of expression and performance. Exploring more applications of textiles in creative computing contexts, as well as computing more broadly, may help us better understand how we can better bridge mass audiences toward better digital and technological literacy. This study has uncovered an innate association we have with textiles, and the potential for it to be a material for education, connection, and mediation. Applying textiles in interactive public installations would help us clarify the medium's potential in connected wider audiences to technological concepts and discourse.

6.2.3 Tangible and Embodied Interactions

Making technological experiences tangible and embodied fosters a deeper and more personalised connection. This project has articulated the importance of multi-sensory embodiment in associating personal agency with broader systems and contexts. Further clarity on how tangible and embodied interactions can be applied to human-AI interaction beyond co-creation may uncover additional ways we can frame and define AI in a tangible manner. Potential for future exploration in tangible representations of AI can be constructed through critical evaluation of the role of tangible and embodied interactions in human-AI relationships.

Appendix A

Appendix A: User Study - Ethics Documentation

The following pages detail the following documents submitted and approved under ANU Ethics Protocol Number H/2024/0995.

- Project Description
- Participant Information Sheet
- Participant Consent Form
- Semi-structured Interview Questions

1 Title

Exploring tactility in Human-AI musical performance through textile interfaces.
Protocol Number H/2024/0995.

2 Background

Short Literature review Familiarity and physicality underpin tangible computing and the development of embodied interfaces [1]. Current research on human-AI collaboration and co-creation manifests through either the visual in two-dimensional drawing and mark making activities, or sonic and music making systems [7, 4, 5]. There is little research directed at tangible and embodied interaction with AI in contexts of musical and artistic performance. Relationships of understanding and trust with AI are a current research direction [6].

Rationale/justification This project aims to fill a research gap at the intersection of tangible interfaces, artistic co-creation in Human-AI interaction, and interactive audiovisual systems. Our overall goal is to further understand the effects of soft materiality as a novel medium for interaction with AI. The participants' insights will help us produce better frameworks for designing and understanding human-AI co-creation in artistic contexts.

Research questions/aims/objectives/hypothesis The research questions for this work are as follows:

1. What roles could tangible and embodied interfaces have in Human-AI collaboration?
2. How do textile interfaces enable interactive arts?
3. How can real-time Human-AI interaction enable trust?

3 Project Design

Methodological approach: We will apply a practice-based research process where a creative arts process is used to test research questions [3]. Using this approach with a small (10) number of participants is appropriate for the exploratory stage of this research and its scale as an Honours project. We will use reflexive thematic analysis [2] to analyse collected data.

Research activities: This research involves asking the participant to use the presented textile interface to create music for around 8 minutes, during which the researcher will take observational notes of the nature of interaction. The interface is physically a large quilt on the floor, so using it involves participants to touch, walk on, press, kneel on. The provided quilt uses a network of conductive wires connected to a Bela Trill Craft controller that picks up the presence of the user. As the user touches parts of the quilt, different sensors are mapped to different sound outputs created in a PureData patch. The AI agent is trained on an array of 16 inputs, each representing the conductivity detected in one sensor. Its output is fed into the same PureData patch for sonic output. After a participatory session, participants will be interviewed by the researcher to gather qualitative data reflecting upon their experience.

Our interview questions will be strictly related to the participant's experience within this session and are included in a separate attachment.

Data Collection/Gathering: Data collected during this study will be:

- audio/video recordings of interviews with participants
- audio/video recordings of musical performances during interviews.

- Sandy's observation notes during the musical performances and interviews

If a participant withdraws from this project, by default, their data will be destroyed and not used. Interviews will be transcribed and subject to qualitative analysis.

References

[1] "Being-in-the-World": Embodied Interaction. In *Where the Action Is: The Foundations of Embodied Interaction*. The MIT Press, 09 2001. `arXiv:https://direct.mit.edu/book/chapter-pdf/2432913/9780262256056\_cad.pdf`, `doi:10.7551/mitpress/7221.003.0005`.

[2] V. Braun and V. Clarke. *Thematic Analysis: A Practical Guide*. SAGE Publications Ltd, London, UK, 2021.

[3] L. Candy, E. Edmonds, and C. Vear. Practice-based research. In *The Routledge international handbook of practice-based research*, pages 27–41. Routledge, 2021.

[4] N. Davis, C.-P. Hsiao, K. Yashraj Singh, L. Li, and B. Magerko. Empirically studying participatory sense-making in abstract drawing with a co-creative cognitive agent. In *Proceedings of the 21st International Conference on Intelligent User Interfaces*, IUI '16, page 196–207, New York, NY, USA, 2016. Association for Computing Machinery. `doi:10.1145/2856767.2856795`.

[5] D. EL-Zanfaly, Y. Huang, and Y. Dong. Sand playground: Designing human-ai physical interface for co-creation in motion. In *Proceedings of the 14th Conference on Creativity and Cognition*, CC '22, page 49–55, New York, NY, USA, 2022. Association for Computing Machinery. URL: `https://doi-org.virtual.anu.edu.au/10.1145/3527927.3532791`, `doi:10.1145/3527927.3532791`.

[6] M. Ghajargar, J. Bardzell, A. S. Renner, P. G. Krogh, K. Höök, D. Cuartielles, L. Boer, and M. Wiberg. From "explainable ai" to "graspable ai". In *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction*, TEI '21, New York, NY, USA, 2021. Association for Computing Machinery. URL: `https://doi-org.virtual.anu.edu.au/10.1145/3430524.3442704`, `doi:10.1145/3430524.3442704`.

[7] C. P. Martin and J. Torresen. An interactive musical prediction system with mixture density recurrent neural networks. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 260–265, 2019. `doi:10.5281/zenodo.3672952`.

Participant Information Sheet
Exploring tactility in Human-AI
musical performance through textile interfaces

1 Researcher

Hello, I am Sandy Ma and I am an Honours student at the Australian National University School of Computing in Canberra. I am a multidisciplinary artist working in the intersections of sound, electronics, and tactility.

2 Project Title:

Exploring tactility in Human-AI musical performance through textile interfaces.

3 General Outline of the Project:

Description and Methodology: This project presents you with an interactive installation where you can interact with an AI agent through a textile interface. You will be able to hear sounds responding to your touch, and see a visualisation of the AI responses accompanying their sounds. The AI will be continuously track your performance and input and respond when you are not interacting with the textile surface. The researcher will take notes during the interaction, and subsequently interview you. Audio and video recordings will be made for the duration of the study session. The interviews, sound and video data will be analysed to produce the findings of this research.

The provided quilt uses a network of conductive wires connected to a Bela Trill Craft controller that picks up the presence of the user. As the user touches parts of the quilt, different sensors are mapped to different sound outputs created in a PureData patch. The AI agent is trained on an array of 16 inputs, each representing the conductivity detected in one sensor. Its output is fed into the same PureData patch for sonic output.

Participants: The participants in this study will be members of the Canberra community who are at least 18 years old and are comfortable moving around and interacting with a floor based interface by way of touching, walking on, pressing, and kneeling on. We will collect data from the participants through interviews. We intend to recruit ten participants.

Use of Data and Feedback: The interview, sound, and video data, as well as notes we take during the session, will be used for research publications such as journal and conference articles. We will share the results of this project with you via email following the data analysis.

4 Participant Involvement:

Voluntary Participation & Withdrawal: Your participation in this project is **voluntary** and you may decline to take part or withdraw from this research without providing an explanation at any time until the work is prepared for publication. You can refuse to answer any interview questions. If you withdraw from this project, by default, your data will be destroyed and not used.

What does participation in the research entail? This research involves you creating music for around 8 minutes with a textile musical interface that we have developed. You will then be interviewed by the researcher to understand your experience. To participate in this research you will fill out an initial questionnaire to allow us to understand your suitability for the study. After you join the study we will contact you by email, phone, or SMS to arrange meeting times. We will ask for your consent to record audio and video in the study session, we will record our discussion and your interaction with the textile system. I will also take notes during the interviews about your responses and interactions with the AI module. The interviews will be transcribed by computer software on ANU devices and we will send you the interview transcript before completing our analysis. We will ask your consent to include quotes from the interview transcript and snippets or screenshots of video recordings of your performances in publications resulting from this research. We will only use video/audio if you consent to it.

Location and Duration: Interviews and research sessions will take place at the Australian National University campus in an enclosed, private room, and will take place individually where there will only be one participant present per session. This project will involve 1 interview and the whole study session will last around 1 hour.

Remuneration: No remuneration is provided to participants.

Risks: There are generally few risks or hazards involved in this project. As this project will have few participants there is a risk that you might be identified as a participant from the resulting publications through descriptions of your experience or a video or image that you consent for us to include. We will attempt to mitigate this risk by de-identifying any reproduction of statements made in interviews and any video that you give us permission to include in research publications. Deidentification processes are further explained in Section 6 Confidentiality. This research is not intended to cover sensitive or uncomfortable topics, so you may refuse to answer any interview questions that you wish and may stop an interview at any time if you are uncomfortable. As the proposed interface is floor based, participants must be comfortable moving near the floor or on their hands and knees.

Benefits: You personally may not benefit from this research, though you will get to experiment with a new musical interface design and contribute to our understanding of how textile interfaces can provide an expressive experience. We hope that this research will help define the role of tangible user interfaces in creative arts.

5 Exclusion Criteria:

Participant Limitation: Participants will not be able to take part in this project if they are younger than 18 or uncomfortable moving on the floor or on hands and knees. We ask that you consent to our recording audio and video of your performance and publishing de-identified video and interview data.

6 Confidentiality:

During the project, data provided by you will be accessible to me (Sandy) and my supervisor (Charles Martin). Your data, including questionnaires, interview recordings, transcripts, video, and audio files will be stored privately during and after the project. Where quotes, video, or images are included in the publications resulting from this research, that data will be de-identified before publication and attributed to a pseudonym (e.g., "P1"). De-identification of images and videos will occur through the blurring or complete omitting of participants' faces. We will protect your confidentiality as far as the law allows. As there will be few participants in this research, it may be possible to re-identify you through descriptions, videos, or images of your work in our research publications. Due to this risk, we ask that you avoid discussing sensitive information during interviews.

7 Privacy Notice:

In collecting your personal information within this research, the ANU must comply with the Privacy Act 1988. The ANU Privacy Policy is available at `https://policies.anu.edu.au/ppl/document/ANUP_010007` and it contains information about how a person can:

- Access or seek correction to their personal information;
- Complain about a breach of an Australian Privacy Principle

by ANU, and how ANU will handle the complaint.

8 Data Storage:

Where: Data will be stored securely on ANU Microsoft OneDrive and downloaded onto Sandy's encrypted and password-protected computer for analysis. Data will be accessible by Sandy Ma and Charles Martin.

How long: Data will be stored for a period of at least five years from the date of any publication arising from the research.

Handling of data following the required storage period: Data will be destroyed following the storage period.

9 Queries and Concerns:

Contact Details for More Information: For further information or any queries regarding this study, please contact Sandy Ma by email: sandy.ma@anu.edu.au or Charles Martin by email: charles.martin@anu.edu.au or phone: (02) 6125 3139

10 Ethics Committee Clearance:

The ethical aspects of this research have been approved by the ANU Human Research Ethics Committee (Protocol H/2024/0995). If you have any concerns or complaints about how this research has been conducted, please contact:

Ethics Manager
The ANU Human Research Ethics Committee
The Australian National University
Telephone: +61 2 6125 3427
Email: Human.Ethics.Officer@anu.edu.au

Australian National University

CONSENT FORM for Research Participants
Exploring tactility in Human-AI musical performance through textile interfaces

1 Consent for Participation

I have read and understood the Information Sheet you have given me about the research project, and I have had any questions and concerns about the project listed here:

____

____

addressed to my satisfaction.

I agree to participate in the project.	YES ☐	NO ☐
I agree to interviews being video and audio recorded.	YES ☐	NO ☐
I agree to the researcher taking notes during the study.	YES ☐	NO ☐
I agree to being identified by pseudonym (e.g., P1) in research outputs.	YES ☐	NO ☐
I agree for de-identified audio/video music recordings appearing in research outputs.	YES ☐	NO ☐

Signature: .... Date: ....

Interview Questions: Exploring tactility in musical AI interaction

Questions for semi-structured interview.

1. Can you describe your initial impressions the musical quilt?
2. How did your impressions of the quilt evolve as over the session today?
3. Can you describe your thoughts on the AI component in this system?
4. What roles did you think that the AI component had in your performance?
5. How do you feel that your performance evolved?
6. Did you feel like you were developing a relationship or collaboration with the AI component in the system? Did you feel trust (or mistrust) when interacting with it?
7. Could you talk about aspects of this experience that you found?
8. Could you talk about aspects this experience that were confusing or frustrating?

Appendix B WHS Hazard and Risk Assessment Template

	Static Risk Assessment No.	Assessment Date	Review by Date	Version
	To be assigned by WHS Officer/Manager or equivalent	**4 Sep 2024**	*4 Sep 2027*	**1**

Name of the Task/Activity/Area/ Hazards to be assessed	Sensor mat interaction in School of Computing offices.	**Top Residual Risk (L, M, H, E)** **L**
Detailed description of the activity/task & location	This involves interacting with a custom fabricated mat in School of Computing offices. The mat is fabricated from a foam puzzle mat with fabric covering and is approximately 2m x 2m. Wire antennas are integrated into the mat which sense when the user is covering different areas with their body. Interaction involves walking, kneeling, pressing and lying on the mat. The mat is located in the open space areas of School of Computing offices and is connected to the Bela computer system by a slim cable.	
School/Service Division	School of Computing	

Location and Supervisor	**Location**	**School of Computer**	**Supervisor**	**Dr Charles Martin**	**Ph**	
Risk Assessment Team Have you completed ANU WHS Risk Management Training? ☒ Y ☐ N **IF NO, DO NOT PROCEED**	**Name**	**Sandy Ma**	**Email**	**Sandy.ma@anu.edu.au**	**Ph**	
	Name	**Charles Martin**	**Email**	**Charles.martin@anu.edu.au**	**Ph**	
	Name		**Email**		**Ph**	
	Name		**Email**		**Ph**	

Who will be affected by this RA?	☐ All people in the location ☒ A group/s of people (list below) ☒ A single person (list below)
Who will be consulted on this RA? (All persons affected or their	*Sandy Ma* *Charles Martin*

representatives needs to be consulted)	
WHS Legal and Other Requirements	Work Health and Safety Act 2011 (Cth) Work Health and Safety Regulations 2011 (Cth) *For other legal requirements, choose from University WHS Legal and Other Requirements Matrix for specific Risk Profile and corresponding requirements and list them here. Alternatively, you can refer to a WHSMS Handbook Chapter in this section.*
Type of RA	☐ **Static RA (long term and > 6 months)** - Send a copy (electronic) to WHS Officer/Manager and keep original locally near the activity/location, accessible to all people affected. ☒ **Dynamic RA (short term and < 6 months or once off)** – Keep the original locally (electronically or physically) near the activity/location, accessible to all people affected.

Risk Assessment Instruction

- This form is used when a documented risk assessment is required in accordance with Appendix A of WHSMS Handbook Chapter 3.1.
- Original risk assessments must be in a convenient location in the local area accessible by all people affected by the risk assessment.
- Risk assessments for static hazards/tasks/activities must be forwarded to local the WHS Officer/Manager for inclusion in the School/Service Division Static Risk Assessment Register.

Follow these steps to complete the risk assessment:

1. Select all applicable hazards from Table 1 below and transfer them into the 'Hazards' column of the Risk Assessment (RA) Form.
2. Enter where and when this hazard exists. This may include specifying during which step(s) in the activity, this hazard exists.
3. Estimate the inherent risk of the hazard (without any controls in place) by using Likelihood against Consequences (defined in Table 2) and the ANU WHS Risk Matrix (Table 3). Record this in the 'Inherent Risk' column of the RA Form.
4. Identify appropriate control measures for each hazard in accordance with the Hierarchy of Control Principle (Table 4) and list them in the 'Control' column of the RA Form.
5. Estimate the residual risk of the hazard after implementing all controls. In estimating residual risk, remember that administrative controls can only reduce the 'likelihood' of an event occurring, not the 'consequences'.
6. Identify any controls that are not already in place as corrective actions in Figtree and ensure that they are implemented before undertaking the activity.
7. Obtain approval from relevant people as identified.
8. Identify if this is a static risk assessment (> 6 months) or dynamic risk assessment (< 6 months).
9. Send a copy of the static risk assessments to WHS Officers/Managers/Equivalent – Keep on file for 7 years.
10. Keep originals of risk assessments in close vicinity of the activities. Dynamic risk assessments can be destroyed 1 year after the activity ceases.
11. Review the static risk assessments and associated safe work procedures in accordance with 3.1.2.6 Step 4: Review Control Measures.

Risk Assessment							
Hazards	**Inherent Risk**			**Control Measures**	**Residual Risk**		
Also list where and when can the hazards present?	**Likelihood**	**Consequence**	**Risk rating**	When control a hazard, always follow Hierarchy of Control Principle to go to the highest possible control before moving to less effective controls (see Table 4).	**Likelihood**	**Consequence**	**Risk rating**
Fall on same level (e.g. slip, trip, wet or unstable surface) Stepping onto the mat, kneeling on the mat, or moving to a lying position could lead to a fall on the same level.	Possible	Minor	Low	**Elimination** • Research participants or users who may have limited mobility for walking, kneeling, or lying on a mat are excluded from studies. **Engineering** • Ensure that area around mat is clear to enable safe walking, kneeling, or lying on the mat. • Ensure that mat is a soft surface and appropriate for kneeling, pressing, or lying without risk of injury. **Administration** • Induction to users to highlight need to take care when walking, kneeling, or lying on the mat.	Unlikely	Insignificant	Low

Risk Assessment							
Hazards Also list where and when can the hazards present?	**Inherent Risk**			**Control Measures** When control a hazard, always follow Hierarchy of Control Principle to go to the highest possible control before moving to less effective controls (see Table 4).	**Residual Risk**		
	Likelihood	**Consequence**	**Risk rating**		**Likelihood**	**Consequence**	**Risk rating**
Use of VR, AI or emerging technology on experiment participants Research participants may feel discomfort when using our "emerging technology" system due to walking, kneeling, pressing, or lying on the mat.	Possible	Insignificant	Low	**Elimination** • Research Participants who may be susceptible to discomfort due to walking, kneeling, pressing or lying on the ground, are excluded from participating in research studies. **Engineering** • Ensure that area around mat is clear to avoid discomfort when walking, kneeling, pressing or lying on the ground. **Administration** • Induction to users to ensure that they are aware of physical movements that they might use with the mat (walking, kneeling, pressing).	Rare	Insignificant	Low

Corrective Actions				
The activity must not be commenced until all controls are in place. List below which controls are currently not in place, who will implement them and by when. *Add additional rows as needed.* Identified corrective actions must be recorded in Figtree.				
List of Controls not in place	**Responsible person/s**	**Figtree corrective action number**	**Timeframe**	**Date Completed**

Approval for risk assessment

If the level of residual risk is assessed as **high** or **extreme**,

1. **Stop the activity immediately**; AND
2. Tag out the plant/equipment; and/or
3. Secure any chemical; and
4. Implement, or seek advice from WHS Officer or Subject Matter Experts to implement, additional controls to reduce the residual risk further to medium [Supervisor signature required];
5. If the above is not possible, seek approval from relevant authority (High – School/Division Director/College Dean; Extreme – COO).
   NOTE: Approval will only be granted in exceptional circumstances after consultation with Associate Director, WEG and/or a Subject Matter Expert. See Chapter 3.1 for details.

Approval required					
Worker conducted RA			**Student conducted RA**		
Residual Risk Level	**Authority required**	**Signature and date**	**Residual Risk Level**	**Authority required**	**Signature and date**
Low	**Author of RA**		Low	**Supervisor**	Charles Martin. 4/9/2024
Medium	**Supervisor**		Medium	**Supervisor**	
High	**School/Service Division Director** or **College Dean**		High	**School/Service Division Director** or **College Dean**	
Extreme	**COO**		Extreme	**COO**	

Appendix B

Appendix: List of Performance Documentation

The following appendix documents links to access audiovisual documentation of the main performances outlined in this thesis.

B.1 Video Recordings of *Touching Wires*

Andromeda is Coming & Artificially Intelligent Friends was a concert featuring Andromeda is Coming (Charles Martin & Alec Hunter), Yichen Wang, and Sandy Ma.

Touching Wires is a 4A LAB Emerging Artist initiative, supported by the City of Sydney Innovations and Ideas grant; a site-specific activation of the 4A LAB, which prioritises research and artworks that are grounded in experimentation, technology and change. The *Touching Wires* opening night performance featured Sandy Ma and Isabelle Laxamana in an improvised movement duet.

- *Andromeda is Coming & Artificially Intelligent Friends* concert (30 May 2024)
  Solo performance at 29:49-38:30
  `https://youtu.be/86yEZquWsPs?si=0h4mSM_3hFb79xVy`
- 4A Lab Opening Night performance (10 October 2024)
  `https://youtu.be/yzJ4E2CvqNI`
- 4A Lab Installation demonstration (16 October 2024)
  `https://youtu.be/E49UbeMH5-I`

Bibliography

Albers, A. (2018). *On Weaving: New Expanded Edition*. Princeton University Press, Princeton. [Cited on page 7.]

Ashktorab, Z., Dugan, C., Johnson, J., Pan, Q., Zhang, W., Kumaravel, S., and Campbell, M. (2021). Effects of communication directionality and ai agent differences in human-ai interaction. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, CHI '21, New York, NY, USA. Association for Computing Machinery. [Cited on page 11.]

Barrow, N. (2024). Anthropomorphism and AI hype. *AI and Ethics*, 4(3):707–711. [Cited on page 55.]

bela.io (n.d.a). gui-send (example). https://learn.bela.io/tutorials/pure-data/communication/graphical-user-interfaces/. Within Bela Examples on IDE. [Cited on page 20.]

bela.io (n.d.b). Programming trill with bela. https://learn.bela.io/using-trill/trill-and-bela/#pure-data. Accessed: 2024-03-07. [Cited on page 20.]

bela.io (n.d.c). Working with trill craft. https://learn.bela.io/tutorials/trill-sensors/working-with-trill-craft/. Accessed: 2024-03-07. [Cited on page 18.]

Benjamin, W. (2008). *The Work of Art in the Age of Mechanical Reproduction*. Penguin Great Ideas. Penguin Books Limited. [Cited on page 12.]

Berdahl, E. and Ju, W. (2011). Satellite ccrma: A musical interaction and sound synthesis platform. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 173–178, Oslo, Norway. [Cited on page 8.]

Berdahl, E., Salazar, S., and Borins, M. (2013). Embedded networking and hardware-accelerated graphics with satellite ccrma. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 325–330, Daejeon, Republic of Korea. Graduate School of Culture Technology, KAIST. [Cited on page 8.]

Berkel, N. v., Skov, M. B., and Kjeldskov, J. (2021). Human-ai interaction: intermittent, continuous, and proactive. *interactions*, 28(6):67–71. [Cited on pages 11 and 13.]

Blandford, A., Furniss, D., and Makri, S. (2016). *Qualitative HCI research : going behind the scenes*. Synthesis Lectures on Human-Centered Informatics. Morgan & Claypool, San Rafael [California. [Cited on page 4.]

Boden, M. A. (2015). Creativity and ALife. *Artificial Life*, 21(3):354–365. [Cited on page 11.]

Braun, V. and Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2):77–101. [Cited on page 5.]

Braun, V. and Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, 11(4):589–597. [Cited on page 5.]

Braun, V. and Clarke, V. (2021). One size fits all? what counts as quality practice in (reflexive) thematic analysis? *Qualitative Research in Psychology*, 18(3):328–352. [Cited on pages 5 and 41.]

Brown, A. R. and Sorensen, A. (2009). Integrating Creative Practice and Research in the Digital Media Arts. In *Practice-led Research, Research-led Practice in the Creative Arts*. Edinburgh University Press, Edinburgh, United Kingdom. [Cited on page 5.]

Camara Halac, F. and Addy, S. (2020). Pathosonic: Performing sound in virtual reality feature space. In Michon, R. and Schroeder, F., editors, *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 520–522, Birmingham, UK. Birmingham City University. [Cited on page 8.]

Candy, L. (2006). Practice based research: A guide. *CCS report*, 1(2):1–19. [Cited on page 4.]

carlos kamas (n.d). Distant explosion. `https://samplefocus.com/samples/distant-explosion`. [Cited on page 22.]

Chang, A. and Ishii, H. (2007). Zstretch: a stretchy fabric music controller. In *Proceedings of the 7th International Conference on New Interfaces for Musical Expression*, NIME '07, page 46–49, New York, NY, USA. Association for Computing Machinery. [Cited on page 8.]

Davis, N., Hsiao, C.-P., Yashraj Singh, K., Li, L., and Magerko, B. (2016). Empirically studying participatory sense-making in abstract drawing with a co-creative cognitive agent. In *Proceedings of the 21st International Conference on Intelligent User Interfaces*, IUI '16, page 196–207, New York, NY, USA. Association for Computing Machinery. [Cited on pages 2 and 12.]

Dourish, P. (2001). "Being-in-the-World": Embodied Interaction. In *Where the Action Is: The Foundations of Embodied Interaction*. The MIT Press. [Cited on pages 2, 9, and 53.]

EL-Zanfaly, D., Huang, Y., and Dong, Y. (2022). Sand playground: Designing human-ai physical interface for co-creation in motion. In *Proceedings of the 14th Conference on Creativity and Cognition*, C&C '22, page 49–55, New York, NY, USA. Association for Computing Machinery. [Cited on pages 2 and 12.]

Frauenberger, C. (2019). Entanglement hci the next wave? *ACM Trans. Comput.-Hum. Interact.*, 27(1). [Cited on pages 10 and 55.]

Gammelgård-Larsen, A., van Berkel, N., Skov, M. B., and Kjeldskov, J. (2024). Designing for human-ai interaction: Comparing intermittent, continuous, and proactive interactions for a music application. In *Extended Abstracts of the 2024 CHI Conference on Human Factors in Computing Systems*, CHI EA '24, New York, NY, USA. Association for Computing Machinery. [Cited on page 11.]

Ghajargar, M., Bardzell, J., Renner, A. S., Krogh, P. G., Höök, K., Cuartielles, D., Boer, L., and Wiberg, M. (2021). From "explainable ai" to "graspable ai". In *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction*, TEI '21, New York, NY, USA. Association for Computing Machinery. [Cited on pages 2 and 12.]

Gonzalez Sanchez, V. E., Martin, C. P., Zelechowska, A., Bjerkestrand, K. A. V., Johnson, V., and Jensenius, A. R. (2018). Bela-based augmented acoustic guitars for sonic microinteraction. In Luke Dahl, Douglas Bowman, T. M., editor, *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 324–327, Blacksburg, Virginia, USA. Virginia Tech. [Cited on page 8.]

Hwang, A. H.-C. and Won, A. S. (2022). Ai in your mind: Counterbalancing perceived agency and experience in human-ai interaction. [Cited on page 11.]

Joshi, T., Biggs, H., Bardzell, J., and Bardzell, S. (2024). Who is "i"?: Subjectivity and ethnography in hci. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems*, CHI '24, New York, NY, USA. Association for Computing Machinery. [Cited on page 4.]

Kannabiran, G. (2023). Post-post-hci. *Interactions*, 30(1):19–21. [Cited on page 10.]

Kara, S. (2023). *Cobalt red : how the blood of the Congo powers our lives.* How the blood of the Congo powers our lives. St. Martin's Press, an imprint of St. Martin's Publishing Group, New York, NY, first edition. edition. [Cited on page 11.]

Kearney, R. (2021). *Coda: Touch and the Coronavirus*, pages 133–140. Columbia University Press. [Cited on page 9.]

Lawton, T., Grace, K., and Ibarrola, F. J. (2023). When is a tool a tool? user perceptions of system agency in human–ai co-creative drawing. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference*, DIS '23, page 1978–1996, New York, NY, USA. Association for Computing Machinery. [Cited on page 11.]

Lee, S., Pham, T., Kong, J., Hoang, T., Kwon, Y., Lee, K., and DiGangi, J. (2024). Investigations by Samsung show irresponsible chemicals management and pollution of Vietnam's environment. Technical report, IPEN, The International Pollutants Elimination Network. [Cited on page 11.]

Lepri, G., Privato, N., and Magnusson, T. (2024). Embodied sketching for neural synthesis. In *Proceedings of the 19th International Audio Mostly Conference: Explorations in Sonic Cultures*, AM '24, page 549–551, New York, NY, USA. Association for Computing Machinery. [Cited on page 8.]

Linthicum, D. (2023). From 'cloud washing' to 'ai washing'. *InfoWorld.com*. Copyright - Copyright Foundry Mar 28, 2023; Last updated - 2024-08-26. [Cited on page 3.]

Ma, S. (2023). fart.wav. Sampled from friend. [Cited on page 22.]

Ma, S. and Wang, Y. (2024). Unspoken. In *Music Proceedings of the International Conference on New Interfaces for Musical Expression*, Utrecht, Netherlands. [Cited on page 13.]

Malloch, J. and Wanderley, M. M. (2007). The t-stick: from musical interface to musical instrument. In *Proceedings of the 7th International Conference on New Interfaces for Musical Expression*, NIME '07, page 66–70, New York, NY, USA. Association for Computing Machinery. [Cited on page 8.]

Martin, C. P. and Torresen, J. (2019). An interactive musical prediction system with mixture density recurrent neural networks. [Cited on pages 2, 12, 17, 25, and 57.]

McCormack, J., Bown, O., Dorin, A., McCabe, J., Monro, G., and Whitelaw, M. (2014). Ten questions concerning generative computer art. *Leonardo*, 47(2):135–141. [Cited on page 55.]

McIntyre, N., Kjewski, L., Munzinger, H., Huppertz, C., and Kotkamp, L. (2024). Paid pennies to train tools of repression: The humans behind moscow's state surveillance. *The Bureau of Investigative Journalism*. [Cited on page 10.]

McNeese, N. J., Demir, M., Chiou, E. K., and Cooke, N. J. (2021). Trust and team performance in human–autonomy teaming. *International Journal of Electronic Commerce*, 25(1):51 – 72. [Cited on page 54.]

mcpecommander (2020). blob. https://editor.p5js.org/mcpecommander/sketches/GPDsjtaXD. CC. [Cited on page 24.]

McPherson, A., Liam Donovan, G. M., Bin, A., Robert Jack, C. H., Pardue, L., and Armitage, J. (2014). Bela. [Cited on page 8.]

Melia, E. (2019). What ? minion sound effects. originally from Minions (2015) via Universal Studios. [Cited on page 22.]

Memis, A. E., Fasciani, S., and Çağrı Erdem (2024). The hyper-ney: An enhanced traditional flute. In Bin, S. M. A. and Reed, C. N., editors, *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 133–137, Utrecht, Netherlands. [Cited on page 8.]

Mice, L. and McPherson, A. P. (2022). Super size me: Interface size, identity and embodiment in digital musical instrument design. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, CHI '22, New York, NY, USA. Association for Computing Machinery. [Cited on pages 3 and 9.]

Miranda, E. R. and Wanderley, M. (2006). *Musical Gestures: Acquisition and Mapping*. A-R Editions, Inc., USA. [Cited on pages 7 and 9.]

Moro, G., Bin, S., Jack, R., Heinrichs, C., and Mcpherson, A. (2016). Making high-performance embedded instruments with bela and pure data. [Cited on page 3.]

Morris, W. (2010; originally published 1888). The revival of handicraft. In Adamson, G., editor, *The Craft Reader*. Bloombury, London, United Kingdom. [Cited on page 10.]

Morrison, L. and McPherson, A. (2024). Entangling entanglement: A diffractive dialogue on hci and musical interactions. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems*, CHI '24, New York, NY, USA. Association for Computing Machinery. [Cited on page 10.]

Morton, T. (2010). *The Ecological Thought*. Harvard University Press, Cambridge, MA and London, England. [Cited on page 55.]

Moura, F. T. (2024). *Artificial Intelligence, Co-Creation and Creativity : The New Frontier for Innovation*. Taylor & Francis Group, Oxford, United Kingdom. [Cited on page 12.]

Nake, F. (2014). Algorithmic art. *Leonardo*, 47(2):108–108. [Cited on page 12.]

Neustaedter, C. and Sengers, P. (2012). Autobiographical design in hci research: designing and learning through use-it-yourself. In *Proceedings of the Designing Interactive Systems Conference*, DIS '12, page 514–523, New York, NY, USA. Association for Computing Machinery. [Cited on page 4.]

Nimkulrat, N. (2010). Material inspiration: From practice-led research to craft art education. *Craft Research*, 1(1):63–84. p67 nifty diagram. [Cited on page 4.]

Nyabola, N. (2024). Chatgpt and the sweatshops powering the digital age. *AlJazeera*. [Cited on page 10.]

Panariello, C. and Percivati, C. (2023). "wypym": A study for feedback-augmented bass clarinet. In Ortiz, M. and Marquez-Borbon, A., editors, *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 174–179, Mexico City, Mexico. [Cited on page 8.]

Papasolomou, I., Melanthiou, Y., and Tsamouridis, A. (2023). The fast fashion vs environment debate: Consumers' level of awareness, feelings, and behaviour towards sustainability within the fast-fashion sector. *Journal of Marketing Communications*, 29(2):191 – 209. [Cited on page 10.]

Pelinski, T., Diaz, R., Temprano, A. L. B., and McPherson, A. (2023). Pipeline for recording datasets and running neural networks on the bela embedded hardware platform. In Ortiz, M. and Marquez-Borbon, A., editors, *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 160–166, Mexico City, Mexico. [Cited on page 8.]

Pigrem, J., Mcpherson, A., Bryan-Kinns, N., and Jack, R. (2022). Sound -¿ object -¿ gesture: Physical affordances of virtual materials. In *Proceedings of the 17th International Audio Mostly Conference*, AM '22, page 59–66, New York, NY, USA. Association for Computing Machinery. [Cited on page 9.]

Pigrem, J. and McPherson, A. P. (2018). Do we speak sensor? cultural constraints of embodied interaction. In Luke Dahl, Douglas Bowman, T. M., editor, *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 382–385, Blacksburg, Virginia, USA. Virginia Tech. [Cited on page 9.]

Proctor, T. (2021). *Theoretical Frameworks*, chapter 1, pages 2–4. Taylor & Francis Group. [Cited on page 12.]

Puckette, M. S. (1996). Pure Data: another integrated computer music environment. In *Proceedings of the Second Intercollege Computer Music Concerts, Tachikawa*, pages 37–41, Tokyo, Japan. Kunitachi College of Music. [Cited on pages 8 and 20.]

radian (2008). Chime 0014.wav. https://freesound.org/people/radian/sounds/62989/. [Cited on page 22.]

Reed, C. N., Strohmeier, P., and McPherson, A. P. (2023). Negotiating experience and communicating information through abstract metaphor. pages 1–16. ACM. [Cited on page 54.]

Robbins, B. G. (2016). What is trust? a multidisciplinary review, critique, and synthesis. *Sociology Compass*, 10(10):972–986. [Cited on page 13.]

Réveillac, J.-M. (2019). *Electronic Music*, chapter 1, pages 1–14. John Wiley & Sons, Ltd. [Cited on page 8.]

Schmeder, A. and Freed, A. (2009). A low-level embedded service architecture for rapid diy design of real-time musical instruments. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 121–124, Pittsburgh, PA, United States. [Cited on page 8.]

sdaau, g. (2018). Block size with puredata on the bela? https://forum.bela.io/d/715-block-size-with-puredata-on-the-bela. [Cited on page 22.]

Skach, S., Shepardson, V., and Magnusson, T. (2024). About time: Textile interfaces for musical expression. pages 521–529. [Cited on pages 13 and 53.]

Skach, S., Xambó, A., Turchet, L., Stolfi, A., Stewart, R., and Barthet, M. (2018). Embodied interactions with e-textiles and the internet of sounds for performing arts. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction*, TEI '18, page 80–87, New York, NY, USA. Association for Computing Machinery. [Cited on page 10.]

Snyder, J. and Polito, D. (2024). The electrobass: A new electronic instrument inspired by the bass guitar. In Bin, S. M. A. and Reed, C. N., editors, *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 602–606, Utrecht, Netherlands. [Cited on page 8.]

The p5.js Team (2014). p5.js library. https://p5js.org/. [Cited on page 20.]

The Research Centre for Gender, Family and Environment in Development and IPEN (2017). Stories of women workers in Vietnam's electronics industry. Technical report, IPEN, The International Pollutants Elimination Network. [Cited on pages 10 and 11.]

United Nations Environment Programme (2024). Ai has an environmental problem. here's what the world can do about that. *UNEP*. [Cited on page 11.]

Visi, F. (2024). The sophtar: a networkable feedback string instrument with embedded machine learning. In Bin, S. M. A. and Reed, C. N., editors, *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 142–148, Utrecht, Netherlands. [Cited on page 8.]

Wang, Y. and Martin, C. (2022). Cubing sound: Designing a NIME for head-mounted augmented reality. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, The University of Auckland, New Zealand. [Cited on page 8.]

Weisz, J. D., He, J., Muller, M., Hoefer, G., Miles, R., and Geyer, W. (2024). Design principles for generative ai applications. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems*, CHI '24, New York, NY, USA. Association for Computing Machinery. [Cited on page 52.]

Whitton, N. and Moseley, A. (2019). *Play and Learning in Adulthood*, chapter 2, pages 12–24. Taylor & Francis Group. [Cited on page 3.]

Wojnowska-Barya, I., Bernat, K., Zaborowska, M., and Kulikowska, D. (2024). The Growing Problem of Textile Waste Generation—The Current State of Textile Waste Management. *Energies*, 17(7):NA. NA. [Cited on page 10.]

Zheng, J., Bryan-Kinns, N., and McPherson, A. P. (2022). Material matters: Exploring materiality in digital musical instruments design. In *Proceedings of the 2022 ACM Designing Interactive Systems Conference*, DIS '22, page 976–986, New York, NY, USA. Association for Computing Machinery. [Cited on page 9.]

Zuckerman, O., Press, V. S., Barda, E., Megidish, B., and Erel, H. (2022). Tangible collaboration: A human-centered approach for sharing control with an actuated-interface. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, CHI '22, New York, NY, USA. Association for Computing Machinery. [Cited on page 13.]