Master's Thesis
Academic Year 2023

Proposal for a Liquid-Based Shape-Shifting Projection System for Enhanced Visual Content

Keio University
Graduate School of Media Design

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A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

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Abstract of Master's Thesis of Academic Year 2023

Proposal for a Liquid-Based Shape-Shifting Projection System for Enhanced Visual Content

Category: Design

Summary

This paper proposes a novel liquid-based shape-shifting projection system, departing from static and flat visual interfaces prevalent in current digital displays. By leveraging the malleable properties of liquids, we aim to transform the digital visual content viewing experience. Our objective, informed by a detailed analysis of existing shape-shifting interfaces, is to develop a highly effective system for shape-shifting performance. This involved material exploration, where we experimented with different materials, incorporating their properties and performances, aiming to find the most effective shape-shifting method for this system. This dynamic system enhances interactivity and enriches the visual experience, setting the stage for future display technology. Looking forward, we foresee this technology's broader incorporation into everyday devices, heralding a new era in visual content interaction.

Keywords:

shape-shifting, projection, interactive interface design, innovation

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Acknowledgements

I am profoundly grateful to Professor Junichi Yamaoka, whose guidance has been instrumental not only in my research but also in numerous aspects of my personal life. His deep knowledge, academic rigor, and genuine care for his students are truly inspiring. His wisdom has lit my way, and his belief in me has helped me persevere during challenging times.

I am equally thankful to Professor Tatsuya Saito, my previous sub-supervisor, whose in-depth discussions and valuable insights have greatly enriched my research. His passion for knowledge and meticulous attention to detail have always pushed me to aim higher and dive deeper into the subject matter.

My sincere appreciation also extends to Yuki Akachi, who has been a constant source of support and inspiration in my research. Her invaluable assistance, creative thinking, and unwavering belief in the importance of our work have significantly influenced my research journey.

Furthermore, I am immensely proud to have been a part of the Future Crafts project. The knowledge I've gained from the collaborative and innovative environment of the project has been instrumental in shaping my academic journey and enhancing my problem-solving skills.

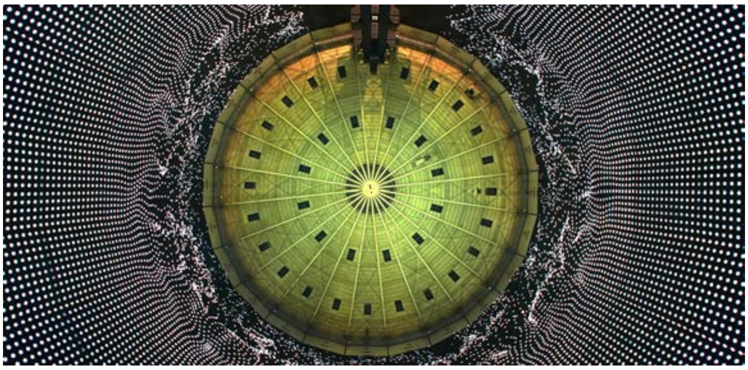
Lastly, I would like to express my gratitude to Keio Media Design for providing me an inclusive platform that fosters curiosity, encourages exploration, and respects diversity. This unique environment has not only equipped me with the skills required for my research but also broadened my perspectives on a personal level.

Chapter 1
Introduction

1.1. Background

In the ever-evolving realm of digital technology, a revolutionary transformation is being witnessed, altering the way visual content is perceived and interacted with [1]. Over recent years, we have seen a rise in various innovative technologies such as interactive surfaces [2], shape displays [3], and spatially immersive displays [4]. These advancements have challenged traditional presentation methods, offering novel avenues of exploration. Yet, despite these strides, current visualization techniques predominantly utilize static, flat interfaces, such as LED screens, thereby confining the dynamism and interactivity of visual content.

This paper introduces and explores a revolutionary visual presentation method — a liquid-based shape-shifting projection system. Utilizing the malleable properties of liquid, this innovative approach aims to push the boundaries of conventional display technology.



(Source: 320° Licht , by URBANSCREEN, 2014[1])

Figure 1.1 Projection Screen Installation "320° Licht"

1.2. Existing Visual Presentation Forms

Existing visual presentation forms in today's digital landscape primarily involve projection screens, holograms, and projection mapping. While offering distinct advantages, these technologies are mostly utilized in settings like exhibitions or live performances that provide substantial technical support. Everyday encounters with immersive digital visual content are far more limited.

Projection screens are recognized for their compatibility and simplicity, serving a broad range of applications. However, their capabilities in facilitating a high degree of interactivity remain constrained [5].

Holograms captivate audiences with their three-dimensional visual experience, providing an unmatched sense of realism and immersion. Nevertheless, they require specific viewing conditions for optimal performance and bear a high implementation cost [6].

(Source: World is Mine by Hatsune Miku, Crypton Future Media, 2010[2])

Figure 1.2 Holographic pop star Hatsune Miku

Projection mapping introduces flexibility in terms of the projection surface, allowing for more creative and immersive visual presentations in customized shapes or forms. However, a key limitation that mars this technology is the static nature of the projection surfaces, limiting dynamic interactions [7].

1 `https://www.urbanscreen.com/320-licht/`

2 `https://www.youtube.com/watch?v=pEaBqiLeCu0`

In each of these technologies, the common constraint is the static and flat nature of the display mediums. The opportunity for more immersive, physically interactive displays in everyday scenarios is apparent, signaling the need for innovative advances in display technology.

(Source: Borderless, by teamLab, 2018[3])

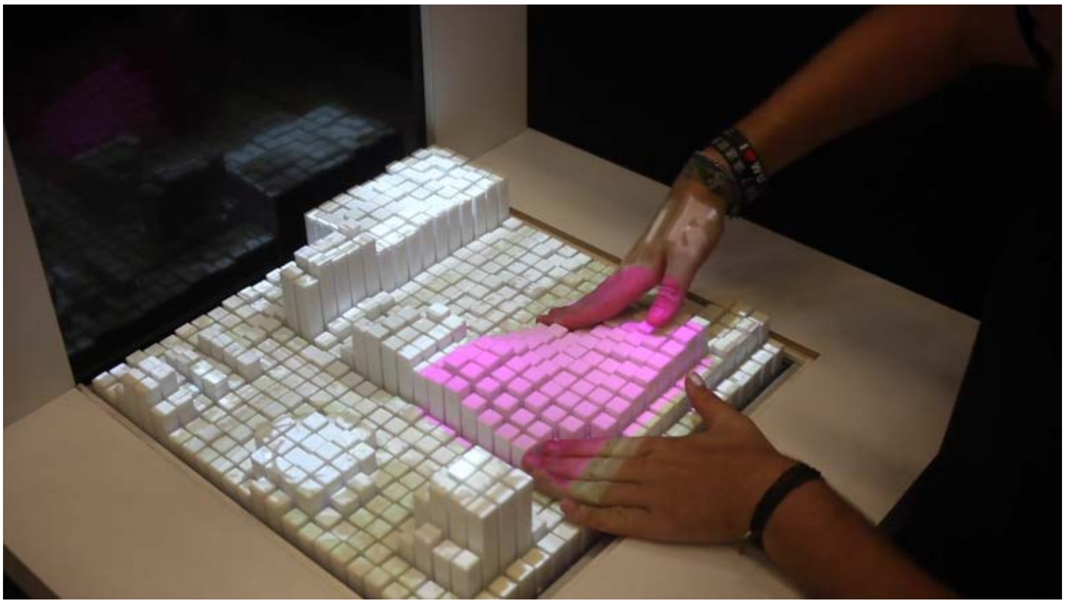
Figure 1.3 Interactive Projection Mapping by teamLab

1.3. The Idea of Shape-Shifting Interface

The concept of a shape-shifting projection interface emerges as a potential solution to limitations that existing displays contain. As the name suggests, this display interface can modify its form dynamically, thereby transforming the visual presentation from mere changes in attributes of visual contents to an interactive

3 https://www.teamlab.art/e/borderless_azabudai/

evolution of the physical display medium itself [8]. This approach not only offers an entirely new visual experience but also enhances the interactivity and engagement of the audience and users.



(Source: Materiable, by Tangible Media Group, 2016[4])

Figure 1.4 Physical Shape-Shifting Interface

1.4. Research Objective

The primary objective of our research is to revolutionize static visual experiences by introducing an innovative shape-shifting projection interface system that enhances dynamic and interactive engagement with visual content. The journey began with an extensive exploration to identify the most effective material that could efficiently manifest shape-shifting properties.

In the process, we critically analyze existing shape-shifting interfaces, addressing key challenges such as interface-graphics alignment. This strategic approach

4 `https://tangible.media.mit.edu/project/materiable/`

allows us to optimize the relationship between dynamic displays and visual content, marking a substantial departure from traditional static and flat displays and underlining our unique contribution to this field.

In the future, we envision this new shape-shifting technology expanding its applications beyond interactive visual content showcases to daily life visual content viewing experiences, paving the way for a significant shift in the interaction paradigm with digital displays and ushering in a new era of enriched visual engagement.

1.4.1 Research Questions

To guide and focus our investigation, and ensure a clear understanding of the research parameters, we start with the following key research questions:

- Considering the advantages and limitations of current shape-shifting displays, such as interface-graphics alignment and increased user engagement, how might these factors inform the development of more effective shape-shifting projection systems?
- In what ways can the properties of specific materials, including their flexibility and durability, be leveraged to enhance the functionality, durability, and versatility of a shape-shifting projection system?
- Is it feasible to develop a shape-shifting display solution that is not only efficient in terms of shape-shifting performances, but also enhances the interactive visual experience for users?

1.4.2 Target Users

The primary audience for our research is visual content creators, particularly designers, and artists who are seeking innovative ways to exhibit and showcase their digital visual content. This new shape-shifting display technology could significantly augment their creative possibilities, offering a novel canvas for artistic expression and interactive presentations.

While our focus is on these creative professionals, we anticipate this technology to have a broader appeal as well. Potential applications could be found in diverse fields such as the consumer electronics industry and interactive advertising. This could range from providing immersive home entertainment solutions to enhancing consumer engagement in advertising.

Ultimately, our goal is to ensure this technology is user-friendly and beneficial across various contexts, exploring innovative possibilities in visual media interaction and expanding the creative landscape for designers and artists alike.

Research Hypothesis

Our hypothesis postulates that introducing this innovative shape-shifting projection interface system could significantly enhance the creation and viewing experience of digital visual content. By evaluating existing shape-shifting displays, we aim to explore a more efficient and simpler method. We anticipate discovering an optimal integration of this shape-changing interface system with dynamic visual content. This exploration could promote an immersive and interactive experience for visual content creators and viewers alike, transforming the way digital visual content is showcased and interacted with across various platforms.

1.5. Thesis Structure

Chapter 1 provides an introductory overview of this research, outlining the background, current practices in visual presentation forms, and the introduction of the concept of the shape-shifting projection interface system. This chapter also introduces the research objective, along with the associated questions and hypotheses.

Chapter 2 provides an analytical overview of existing shape-shifting interfaces in three categories. It examines their properties, focusing on their limitations and potential improvements, thus setting the stage for the inspiration of possible prototype designs for experimentation.

Chapter 3 discusses the material exploration and concept development of the initial prototypes. It includes feedback from exhibitions where these were showcased, and insights gained from experiments conducted by research team we belong to. This chapter then transitions to the conception of the liquid-based shape-shifting projection system based on these insights and new research points.

Chapter 4 delves into the concept and design of the liquid-based projection system in detail, including specific implementation steps, hardware testing procedures, and an exploration of the unique characteristics offered by fluid variations as a display medium.

Chapter 5 focuses on the evaluation of the liquid-based projection system based on feedback from a projection experiment at KMD (Keio Media Design), and includes a comparative assessment between one of the prototypes from the design development and the final liquid-based projection system. It also discusses potential improvements and optimizations derived from these experiments.

Chapter 6 presents the conclusion of this research, highlighting the novel contributions of the liquid-based projection system to the field of interactive visual content display. It also outlines potential directions for future work, with an emphasis on expanding its applications to everyday content viewing experiences.

Chapter 2
Related Works

In this chapter, we will delve into several preceding research projects that studied shape-shifting display interfaces. These projects have approached shape-shifting displays from various research angles and application contexts, each contributing unique insights and perspectives. For clarity and in-depth analysis, we've categorized these works into three groups based on their distinctive characteristics and properties.

Our focus will be on analyzing the merits and limitations of each project, particularly on the materials employed and the fabrication techniques utilized. We will also examine the contexts of their application, and the specific methods they've deployed to achieve shape-shifting performance. It is through this detailed study that we aim to uncover potential materials and techniques that could contribute to the development of our shape-shifting display system.

This analysis will guide our subsequent material exploration and experimentation phases, enabling us to understand the challenges of developing an innovative shape-shifting system. At this stage, we remain open to a wide spectrum of potential materials, allowing the outcomes of our study and experiments to define the most effective material for our design.

2.1. Shape-Shifting Projection Surfaces

The first category we want to introduce is "shape-shifting projection surfaces", which presents a innovative approach in the field of visual presentation technology. These surfaces distinguish themselves by their ability to alter their form dynamically, accommodating a myriad of spatial and visual configurations. The transformation of surface geometry allows for an interactive and immersive visual experience, challenging traditional static projection surfaces.

Key characteristics of shape-shifting projection surfaces include:

- **Dynamic projection mapping**: Visual content is projected onto surfaces that can morph and change, adding a new dimension of interactivity and perception.
- **System control via Leap Motion or similar technology**: The transformation of the surface geometry and alignment of the projected visual content is often controlled by motion tracking technology, such as Leap Motion [9]. This technology tracks user hand movements in real-time, allowing for an intuitive interface to control the visuals.
- **Real-time projection mapping**: With shape-shifting projection surfaces, real-time projection mapping is a crucial aspect. This enables the visual content to adapt immediately to the changes in surface geometry, maintaining alignment and continuity.
- **Motion tracking accuracy**: For the dynamic projection to be successful, accurate motion tracking is require [10]. This ensures the real-time adaptation of visual content to the shifting projection surface.

In the following subsections, we delve into two representative works in the field of shape-shifting projection surfaces: "MEMESIS" and "The Aether Project".

2.1.1 "MEMESIS"

MEMESIS, devised by Steven T. Wong, is an augmented kinetic sculpture that uses rigid origami principles to create a shape-shifting projection surface[1](Figure:2.1). It challenges the conventional passive screen concept, evolving in tandem with the projected animations.

Utilizing Miura-ori and v-pleat cell units, MEMESIS achieves a dynamic, transformable surface. The sculpture's interplay with projected light creates a unique

1 `https://digitalmedia-bremen.de/project/memesis-shape-shifting-projection-surfaces/`

visual experience, manipulating depth perception through virtual shadows and patterns.

Overall, MEMESIS demonstrates the potential of dynamic, shape-shifting projection surfaces in augmenting visual presentation. This concept aligns with the core of our research into innovative projection interface techniques.

(Source: MEMESIS, by Steven T. Wong, 2015[2])

Figure 2.1 Geometrical Augmented Kinetic Sculpture "MEMESIS"

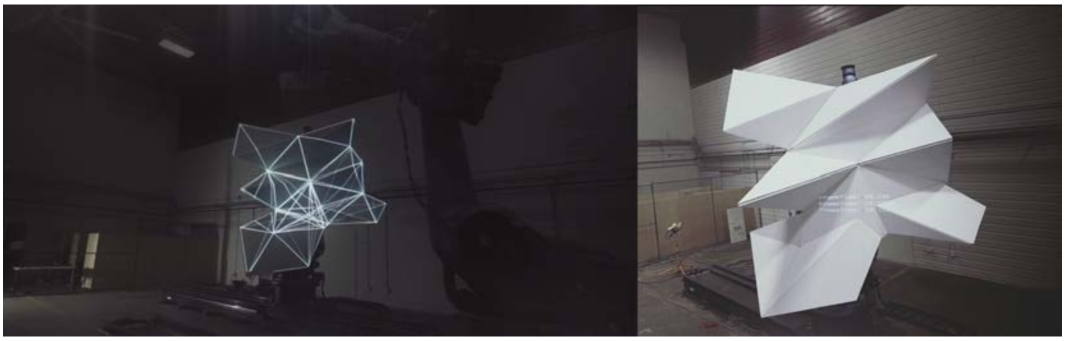
2.1.2 "The Aether Project"

The Aether Project, devised at UCLA, is an exemplary fusion of interactive architecture, robotic actuation, and real-time projection mapping[3](Figure:2.2). Guided by the aspiration to imbue architectural technology with autonomous intelligence,

2 `https://vimeo.com/133145387`

3 `https://refikanadol.com/works/the-aether-project/`

it employs a Leap Motion system to synchronize robotic movement with dynamic visual projection. This project explores human-robot interaction, transforming the norms of architectural and spatial design.



(Source: The Aether Project, by Refik Anadol, 2014[4])

Figure 2.2 Robotic Interactive Architecture "The Aether Project"

2.2. Deformable Interface on a Flat Surface

This chapter delves into the 2nd category we want to introduce, which is "Deformable Interfaces on a Flat Surface". Unlike the previous category, these systems involve the transformation on "flat" interfaces, essentially creating a dynamic, tactile canvas for digital information [11]. This is achieved through "physical pixels" that alter their form on a flat surface, driven by underlying digital inputs.

Characteristically, these interfaces:

- **Physical Pixels**: They consist of "physical pixels" that change form, providing a tangible presentation of typically flat digital content [12].
- **Digital to Physical Transition**: They have a unique capacity to convert digital information into a physical format, thus, connecting the divide between the digital and physical world. [13].

4 `https://vimeo.com/84539876`

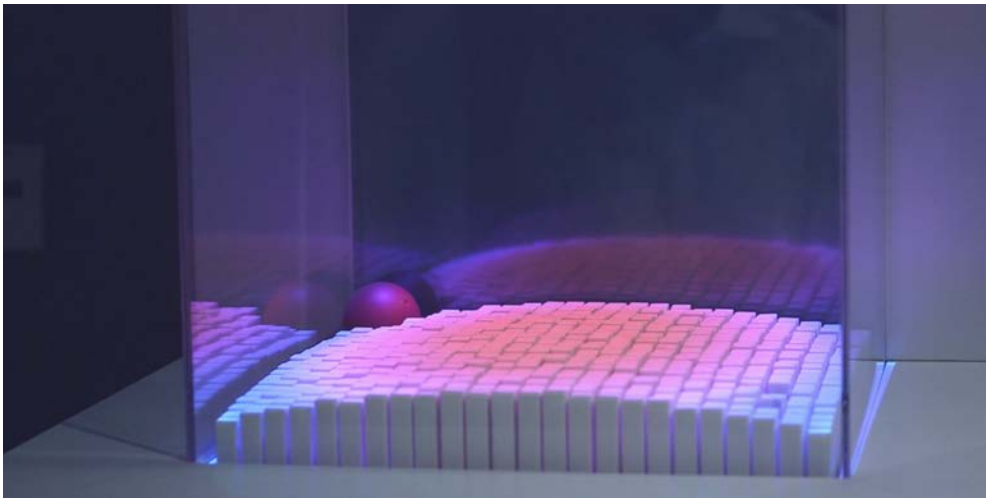
- **Special Materials**: These interfaces leverage specific materials that are both flexible and durable enough to endure the deformations, thereby maintaining their integrity and functionality over time.

These aspects lend deformable interfaces an exciting potential in terms of user engagement and interactive capabilities, changing the way we perceive and interact with flat surfaces in a digital environment.

Two exemplary projects demonstrating these characteristics are "inForm" and "COLORISE". In the following subsections, we will undertake a detailed exploration of these two projects, looking at their construction, operation, and impact on display technology.

2.2.1 "inForm"

The "inForm" interface developed by Tangible Media Group at the MIT Media Lab provides a standout example of a deformable interface on a flat surface [14].



(Source: inFORM at Cooper Hewitt, by Tangible Media Group, 2014[5])

Figure 2.3 Projection on Physical Pin-Based Pixels of "inForm"

5 https://tangible.media.mit.edu/project/inform-at-cooper-hewitt/

As a shape-display technology, it uses a dynamic pin matrix to physically manifest digital information, presenting a new way of interacting with digital content[6]. A customized inFORM display was showcased at New York's Cooper Hewitt as part of the "Tools: Extending our Reach" exhibit. It incorporated projection technology for enhanced visual effects(Figure:2.3). Characteristics and attributes of "inForm" to be highlighted include its physical pixel-based interface, its ability to transfer digital data to the physical realm, and its utilization of special materials or technologies to enable this transformation.

2.2.2 "COLORISE"

Moving from physical representation of digital information to more visually oriented interaction, "COLORISE"(Figure:2.4) is another compelling instance of a deformable interface on a flat surface.

(Source: COLORISE, by Yasuaki Kakehi Laboratory, 2018[7])

Figure 2.4 Inflatable Color-Changing Display "COLORISE"

6 https://tangible.media.mit.edu/project/inform/

7 https://xlab.iii.u-tokyo.ac.jp/projects/colorise/

It has revolutionized the interface landscape by creating an inflatable, color-changing display that doesn't rely on light-emitting devices. This allows for the translation of diverse color patterns from the digital world into a tangible form. The pixels also possess a touch sensing function, facilitating intuitive user interactions and enhancing the user's engagement with the interface [15]. "COLORISE" represents a breakthrough in creating interfaces that not only shape-shift but also deliver tactile feedback and 2.5D motion. The project's potential for enhancing physical interactivity through simultaneous color and shape transformations emphasizes its significance.

2.3. Soft Material Projection

In this chapter, we delve into the concept of "Soft Material Projection", the 3rd category of our study. Such projection surfaces are fundamentally soft, flexible, and light weight, allowing them to be suspended in the air and to reshape in response to elements such as wind or airflow. These surfaces offer a sense of freedom and dynamism rarely found in traditional rigid screens. Their unique traits include:

- **Soft and Airborne**: These surfaces are lightweight and soft enough to be suspended in the air, allowing for a unique floating visual experience.
- **Responsive to Air Flow**: They can change shape in response to air movement, adding an element of unpredictability and organic motion to the viewing experience.
- **Enhanced Freedom**: Soft materials can conform to numerous shapes and movements, providing more flexibility in design and visual presentation.
- **Integrated Lights and Content**: These surfaces can incorporate LED lights or have moving content projected onto them, creating an immersive, dynamic visual experience as the surface and the content interact.

To understand the practical applications of this category, we will look into two attractive examples: the stage design of "Maybe the Wind" from Sakanaction's live performance “SAKANAQUARIUM2017 10th ANNIVERSARY” and “Gauze” from G-Rockets’ performance piece “Material”.

2.3.1 Sakanaction - Maybe the wind (LIVE)

The stage design of “Maybe the Wind”, performed at Sakanaction’s live concert, “SAKANAQUARIUM2017 10th ANNIVERSARY”, is a great example of “Soft Material Projection”. This design utilized long silks placed strategically in the audience aisles. Lightweight, fluid, and flexible, the silks embodied the soft and pliable characteristics. Suspended in the air and animated by motorized fans, the silks floated and danced around the venue, changing shape and form in accordance with the wind’s whims(Figure:2.5).

(Source: Maybe the wind(LIVE), by Sakanaction, 2017[8])

Figure 2.5 Light Projection on Soft Silk in “Maybe the wind”

The visual impact was further magnified by the use of blue LED lights projected onto the silks. As they moved with the wind, the LED images morphed and flowed, creating a stunning visual effect akin to “visible winds”. This transformation of the soft projection surface, combined with the dynamic visuals, produced a captivating viewing experience.

8 https://youtu.be/OR_7ycQAWhU

This stage design demonstrated the extraordinary potential of soft material projection in creating engaging, immersive, and aesthetically pleasing shape-shifting interfaces.

2.3.2 "Gauze" from G-Rockets' s Performance "Material"

A mesmerizing performance piece, "Gauze", is part of G-Rockets' Performance "Material". In this piece, a large organdy cloth gauze takes center stage, illustrating the immense versatility and aesthetic potential of soft materials in projection-based performances. This gauze is not a passive canvas, but an active participant in the performance, inflating with air, soaring towards the ceiling, and interacting with lighting effects to create a surreal, dream-like atmosphere(Figure:2.6).

(Source: "Gauze" from "Material" Performance, by G-Rockets, 2018[9])

Figure 2.6 Light and Contents Projection on Organdy Cloth in "Gauze"

9 https://g-rockets.jp/performance/material/

The gauze's transformative ability is further highlighted in the "Butterfly Gauze" segment. The cloth morphs into a large butterfly shape, symbolizing an intricate interplay between form and movement. As it gracefully flutters through the performance space, the butterfly gauze brings an extra layer of depth and beauty to the classical music accompanying the performance.

This implementation of soft material projection showcases the possibilities of employing flexible materials to alter space dynamically and dramatically, opening new opportunities for creative tangible projection surface design.

2.4. Chapter Summary

In the exploration of three distinct categories above, we've found valuable insights in the into innovative shape-shifting projection interfaces. Each category boasts its own unique set of characteristics, advantages, and disadvantages.

"Shape-Shifting Projection Surfaces", such as "MEMESIS" and "The Aether Project", conduct dynamic projection mapping on moving surfaces. They present a remarkable advantage in real-time spatial adaptability and synchronization of visuals with surface geometry. However, this requires precise motion tracking and control systems, posing potential challenges in execution and maintenance.

"Deformable Interface on a Flat Surface", represented by "inForm" and "COLORISE", effectively bridges the digital and physical worlds. They bring an added dimension of interactivity by transforming digital information into a tangible form. Although this novel approach opens up numerous interactive possibilities, it also demands specific materials and complex mechanisms for the pixels to function as intended.

"Soft Material Projection" shows the essence of freedom and adaptability in design. The stage design of Sakanaction's live performance and G-Rockets's performance illustrate how lightweight materials, suspended in air, can dance with the wind and the projection lights, creating an ethereal viewing experience. While this approach allows for fluid, organic movements, it is inherently dependent on environmental factors like wind and lighting conditions, limiting its applicability in certain settings.

These explorations have inspired our future research, indicating the potential directions of dynamic mapping on deformable surfaces, exploration of new materials, and manipulation of environmental factors. Importantly, these categories are not mutually exclusive. Their intersections could potentially ignite the next leap in interactive design and shape-shifting projection interfaces, setting the stage for our material exploration phase.

Chapter 3
Design Development

Drawing from the valuable insights and concepts gained from various research projects analyzed in Chapter 2, we have shaped our first two prototypes. This chapter outlines the development and conceptualization of these prototypes, detailing the experiments conducted and the feedback received from various exhibitions and workshops where they were showcased. Each phase of our prototype development and experimentation offered us several new ideas, insights, as well as challenges. These experiences guided our design process, leading us towards innovative approaches for future designs.

Following the development of the first two prototypes, we also had the opportunity to experiment with a new type of display developed by Yuki Akachi, the leader of the Display Team—a group of students in Future Crafts researching display-related topics. This experiment, which took place after the creation of our initial prototypes, offered additional insights and inspirations. Drawing from the experience of working with this new type of display and combining these learnings with the insights from our first two prototypes, we were able to further innovate and refine our own designs. As such, this chapter will also detail this experimental phase and discuss its influence on our design evolution.

3.1. Pin Display+Telescopic Structure

3.1.1 Design Concept

In this section, we introduce the design concept of our first prototype "Pin Display + Telescopic Structure". This concept is primarily inspired by "inForm", a related work discussed in Section 2.2.1. We aim to leverage the "dynamic pin matrix", a distinguishing feature of “inForm”, and combine it with telescopic structures, which is a shape-shifting geometric structure, to achieve more flexibility and dimensions in movement.

The principle of operation involves placing 4 to 9 telescopic structures arranged in a grid formation on the actuating pins of the pin display. As the pins ascend and descend in diverse patterns and frequencies, they drive the transformation of the telescopic structures into various forms and shapes (Figure:3.1).

Inspired by “MEMESIS”, another related work we discussed in section 2.1.1, we experimented with overhead projection to display visual contents such as images and video footage on the geometric shape-shifting surfaces of the telescopic structures. This allowed us to evaluate the visual impact of this design concept in action, further exemplifying the potential of integrating projection with dynamically transforming structures.

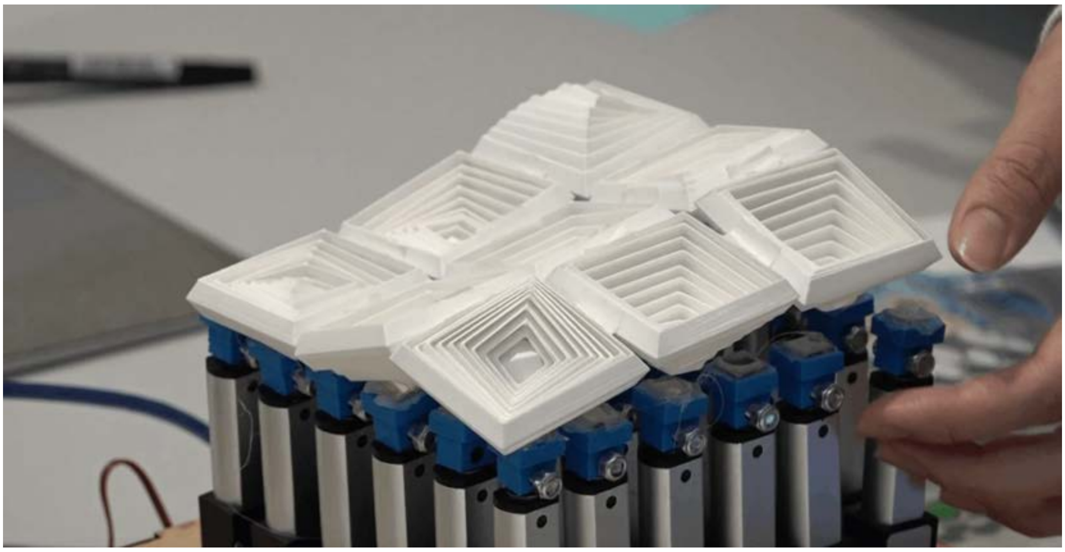


Figure 3.1 Pin Display+Telescopic Structure

Telescopic Structure

Telescopic structure is one of the key components of our first prototype. It is a flexible module that enables diverse shape changes such as parallel, vertical, and rotational motion in one single structure modeling by Autodesk 3ds Max and 3D printed by PLA material(Figure:3.2).

The module presents a unique characteristic during movement: the transformation between states of density and sparsity. This is possible due to the nested structure, composed of layers at varying angles, allowing free deformation.

In its closed state, the module enables two-dimensional translations and rotations within a plane. When extended, it offers the liberty of three-dimensional deformation, granting complete control over the module in all directions. We employed this structure as our shape-shifting interface in the first prototype experiment, investigating its performance when combining with pin display.

To explore variations, we also 3D printed this specific type of structure in different sizes. The insights gained from these different dimensions provide a deeper understanding of the potential and flexibility of telescopic structures in shape-shifting displays.

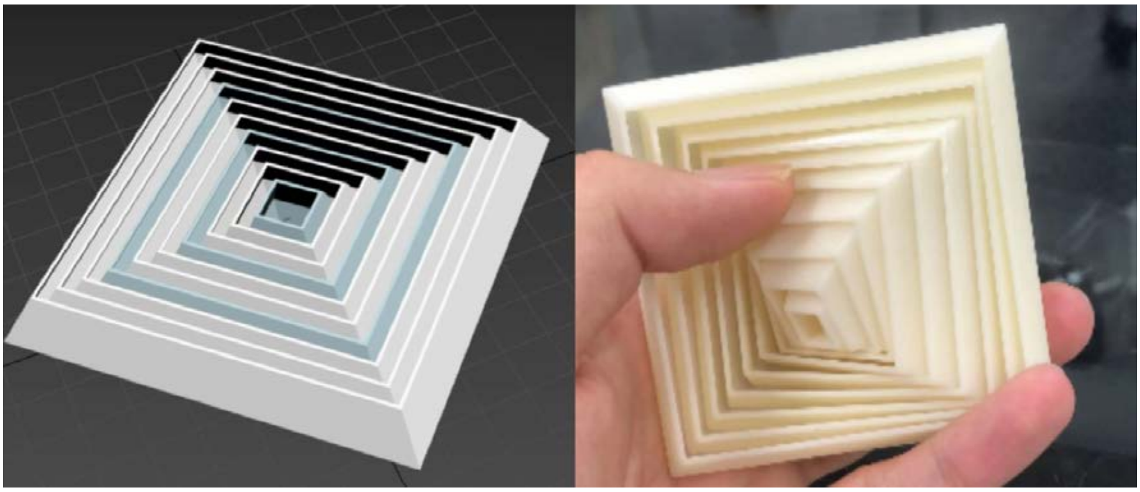


Figure 3.2 3D-Printed Square-Shaped Telescopic Structure

Pin Display

Pin display (Figure:3.3) is another key component of our first prototype. This self-made customized display is primarily composed of a ELEGOO MEGA 2560 R3 board[1], which serves as the base, and 36 LA-T8 linear actuators[2]—arranged in a six-by-six grid—that can move up and down, controlled by Arduino programming via a PC. The movements made by these linear actuators support the dynamic shape-changing capacity of the telescopic structure.

To ensure stability and precision, the linear actuators are carefully positioned in a custom-made wooden holder. The holder is designed to maintain exact spacing between each actuator, an essential aspect for the coordinated functioning of the display. This wooden holder is crafted using laser cutting, ensuring precise cuts and a tight fit for the linear actuators. The combination of these elements allows the pin display to be stable, accurate, and capable of complex shape changing.

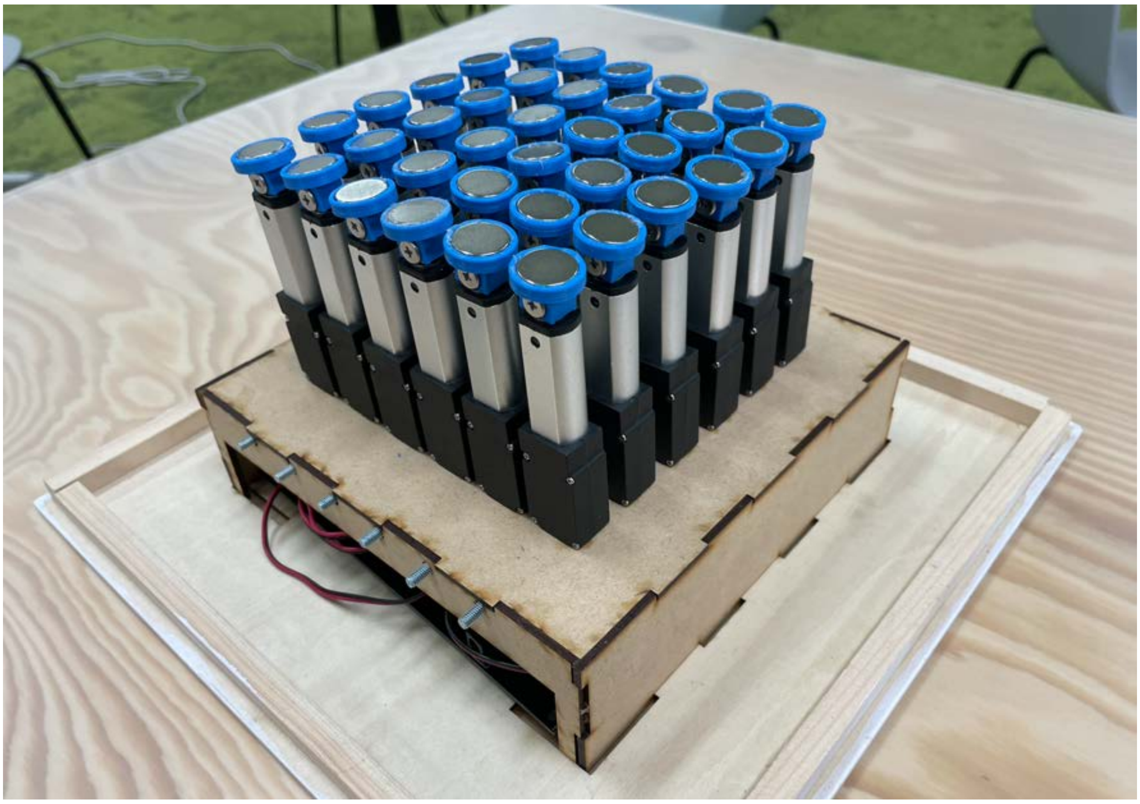


Figure 3.3 Pin Display

1 https://www.elegoo.com/en-jp/products/elegoo-mega-2560-r3-board

2 http://www.gomotorworld.com/pd?product_id=64

3.1.2 Workshop of NTV's Joint Research 2022.05.27

Our first prototype was presented at a workshop held by Nippon TV's R&D Lab on May 27, 2022. Themed "Research and Development of Experiential Media Technology that Transmits the Five Senses"[3], the workshop was part of the joint research initiative that Future Crafts, the lab to which we belong, collaborated with NTV on. The aim was to explore innovative media expressions that bridge physical materials with digital mediums[4].

We utilized this opportunity to test our prototype in a potential application scenario related to contents viewing experience. Our setup included projecting overhead shot images onto the dynamically changing surface of our prototype. This simulation was envisioned as an application for potential TV programs such as geography education by projecting images of mountains, maps, and land forms onto the dynamic shape-shifting surfaces of the prototype (Figure:3.4). The interactive nature of the projected images, paired with the moving telescopic structures and pin displays brought the static images to life, making them visually more vivid and interactive.

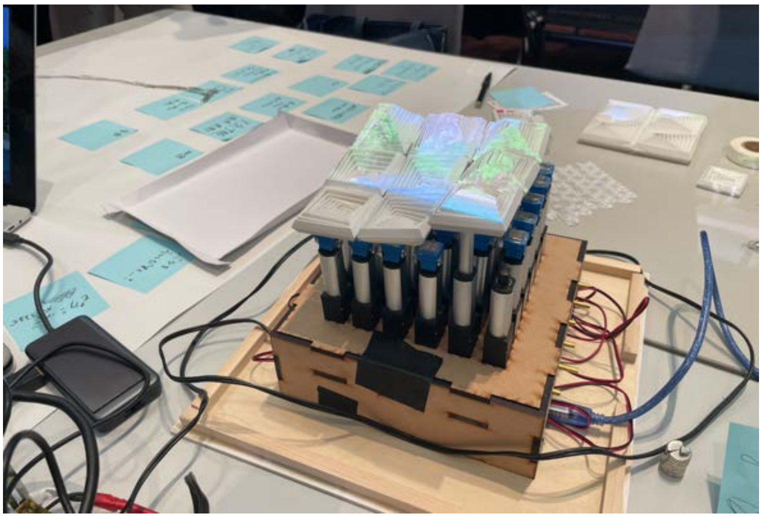


Figure 3.4 Workshop in NTV on May 27th, 2022

3 https://www.ntv.co.jp/info/pressrelease/20220201.html

4 https://note.com/ntvrdlab/n/nae5816297d38

After this workshop, we gathered valuable insights into possible applications and physical interactions that shape-shifting interface could facilitate. This experience informed new concepts and improvements in our design development process.

3.1.3 KMD Plenary Meeting 2022.06.10

This prototype was also showcased at the KMD Plenary Meeting's project showcase session on June 10, 2022. For this showcase, we experimented with a playful animation scenario - "Surfing Man".

We created a simulation of "ocean" by projecting a video footage of giant waves onto the dynamic shape-shifting telescopic structures. The structures, together with the pin displays, mimicked the motion of ocean waves. To further enhance this visual scenario, we placed a small paper toy of a "surfing man" on top of the moving structures. We also precisely set the Arduino programming to ensure that the movements of the pin display and the telescopic structures matched with the projected video, creating a visual representation of "real ocean waves" with a man "surfing" on them. Many visitors commented that this physical animation was interesting and playful, both in terms of visual forms and shape-shifting movements (Figure:3.5).

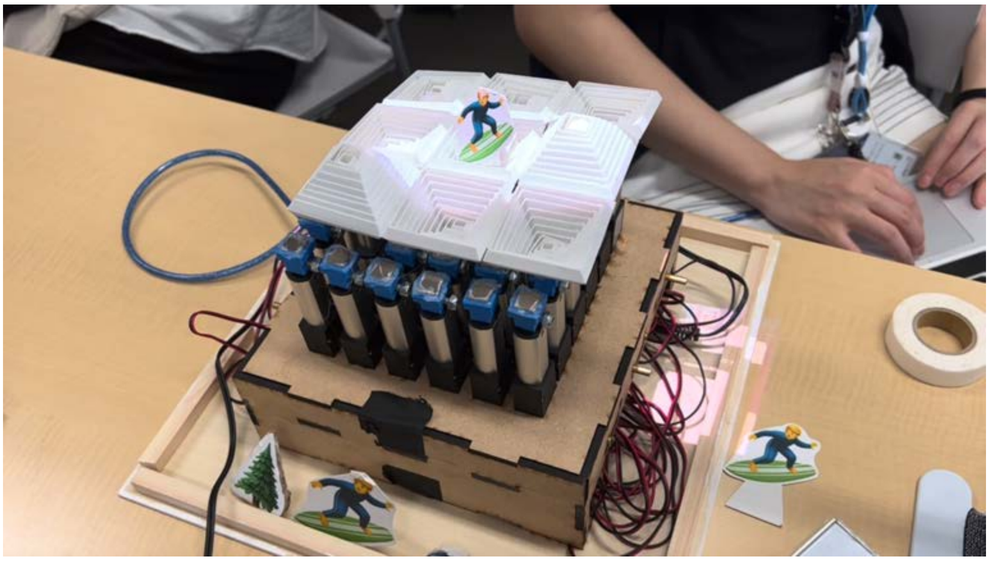


Figure 3.5 Plenary Meeting on June 10th, 2022

This experiment provided us with new insights into the potential interactions that could be created by combining visual content with additional physical elements, thereby enhancing our prototype's ability to provide more unique and interactive experiences.

3.1.4 Problems and New Research Points

This section addresses the issues we encountered with our first prototype and outlines the new research paths these challenges have uncovered.

Although we gained new insights from our experiments in sections 3.1.2 and 3.1.3, we also faced several difficulties present obstacles that need to be resolved in our next prototype. These include:

- The movements of the telescopic structures did not perfectly match the grid of the pin display, which led to instances where some telescopic structures fell off the pin display when the pins actuating.
- The precise design needed for the telescopic structures to match each pin of the display limited the range of form variations that could be executed.
- The sizes of telescopic structures that could fit onto the pin display were also limited.

The limitations above significantly constrained the shape-shifting potential of our first prototype.

To address these challenges, we came up with new research points before starting our second prototype:

- What materials could be employed as the surface of a shape-shifting display considering characteristics like hardness/softness, magnetism, luminescence, etc.?
- How can we enhance the flexibility and freedom of movement by utilizing the characteristics of material itself?
- How can we incorporate more features from the works we analyzed in Chapter 2?

These considerations and the analysis of the issues faced with the first prototype directed the design approach for our next prototype.

3.2. Floating Pixels+Projection Mapping

3.2.1 Design Concept

Our second prototype, "Floating Pixel+Projection Mapping", is designed to address the limitations we encountered with the range of form variations in the telescopic structures used in our first prototype. Informed by the new research point of enhancing flexibility and degrees of freedom through material characteristics, the emphasis for this prototype is on increased freedom of movement and the introduction of randomness effects.

Figure 3.6 Floating Pixels+Projection Mapping

The design concept for this version drew inspiration from "COLORISE", a project mentioned in Chapter 2.2.2, as well as some unique characteristics of works within the "Soft Material Projection" category, which we discussed in Chapter 2.3. "COLORISE" demonstrated the use of real-world physical pixels created from specialized materials. In our second prototype, we've adapted this concept but chosen to use more common and cost-effective materials for the physical pixels.

The objective was to give these physical pixels greater degrees of freedom in their form-changing movements, regulated by a combination of external factors and inherent characteristics of the physical pixels themselves, such as water flow and magnetism (Figure:3.6). This approach aims to achieve an enhanced sense of unpredictability and organic visual effects, inspired by the characteristics found in "Soft Material Projection". Additionally, we will incorporate the use of projection mapping in our experiment, aiming to exploring the various visual impacts on this design concept.

Magnetic Floating Pixels

The floating physical pixels serve as the primary medium of the shape-shifting interface of this prototype. These physical pixels (Figure:3.7), 3D printed in 8mm sphere-shaped from magnetic PLA filaments containing iron[5] and painted in white to maximize the projection effect, are designed to respond to both the water flow and magnetic interaction.

Figure 3.7 Magnetic Floating Pixels

5 https://amzn.asia/d/2oRFv8I

The magnetic force is generated by the actuating pins of the pin display (the one we used in our first prototype), each equipped with a strong magnet. When these pins move, they create a magnetic field that influences the physical pixels, which float freely in the water. This unique interplay allows the pixels to cluster and form shapes when the magnets on actuate pins reach their highest point. The magnetism within the pixels, combined with their inherent freedom of movement, ensures that they respond dynamically to the magnets, enabling shape-shifting capabilities. In total, approximately 200 physical pixels were used in the experiment.

Device Assembly

The device assembly is composed by the pin display, a cylindrical water tank, floating physical pixels, and an overhead projector (Figure:3.8). The pin display, one of the shared elements with the first prototype, controlled by an Arduino base programming, actuates the linear movement of the magnets up and down, which influences the physical pixels floating in the water. When a water pump is activated, it creates a uniform water flow that directs the motion of the pixels within the tank.

The water tank, coated internally with "True Black Muso" model paint[6] sets the "platform" for the pixels' performance. This water-based paint offers a higher total reflectance in the visible spectrum compared to regular black acrylic paint, creating a deep black backdrop that minimizes light reflections. This ensures a purer projection of visual contents on the white physical pixels.

The overhead projector, another shared element with the first prototype, combines visual content with the patterns formed by the physical pixels. This allows a flexible presentation of digital information, which involves with the dynamic movement of the pixels, creates spontaneous and engaging changes on the visual effects. This assembly as a whole fosters a more immersive and unpredictable visual experience.

6 https://www.ko-pro.tech/musoublack/

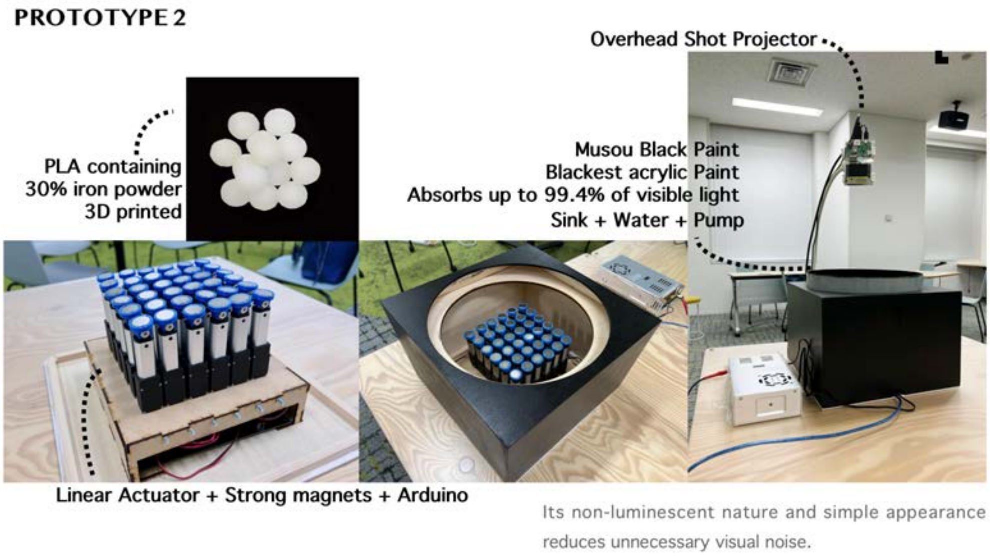


Figure 3.8 Device Assembly of Floating Pixels

3.2.2 Projection Experiments

To ensure the performance and capability of our second prototype, we conducted two projection experiments to test the device and its hardware.

The first experiment was focused on exploring the visual impact of projecting different content onto the physical pixels in various forms, essentially examining the interplay between pixel patterns and visual content.

The second experiment concerned the synchronization of pixel motions and visual content. We controlled the pattern change of the pin display via Arduino programming, thus enabling corresponding shifts in the forms of the physical pixels. To ensure precise and accurate alignment of the projected video content with the patterns formed by the physical pixels, we designed the video content to be precisely projection-mapped onto the physical pixels.

Combination of Pixel Patterns and Visual Contents

For this experiment, we conducted two tests. The first involved setting random patterns for the physical pixels, with no specific meaning attached to the shapes formed by the pixels. We then projected a motion graphics video onto these patterns to observe the visual result of animated video content playing on the changing patterns formed by the physical pixels (Figure3.9).

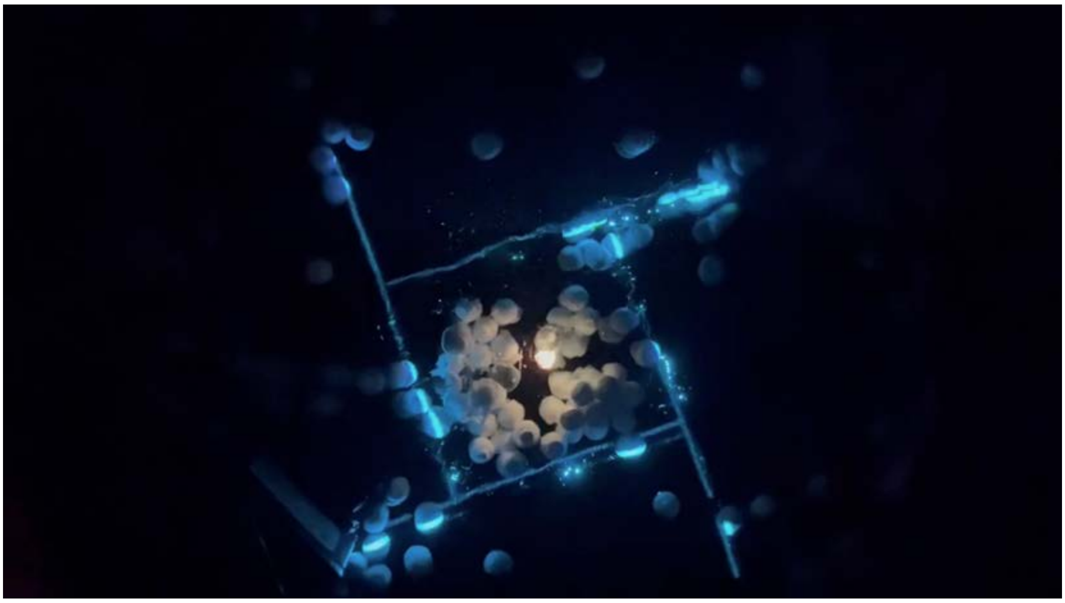


Figure 3.9 Motion Graphics Projection Experiment with Floating Pixels

The second test involved assigning specific symbol patterns, such as English alphabets, to the physical pixels. We then evaluated the aesthetic impact of projecting animated motion graphics onto these symbol-shaped pixels (Figure:3.10)

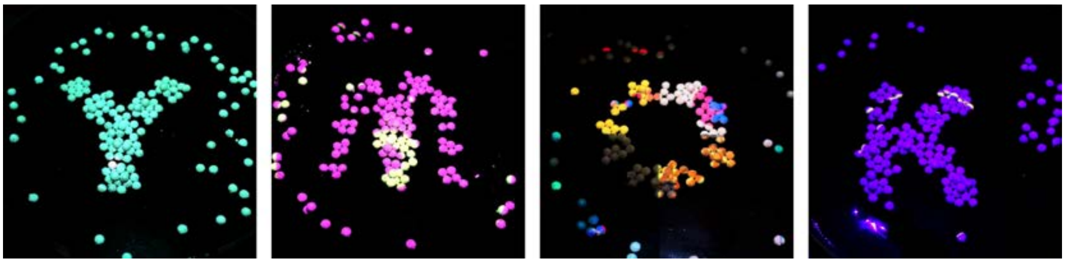


Figure 3.10 Alphabets of “Y”, “M”, “O”, “K” formed by pixels

Synchronization of Pixel Motions and Visual Contents

The second experiment involved setting the patterns of the physical pixels into simple shapes like squares, rectangles, and arrows. We then created a motion graphics video for projection, using Adobe After Effects, and applied shape masks to constrain the video to the shapes corresponding to the patterns formed by the physical pixels. The goal was to explore the visual effects when the projected content is synchronized with the shape of the physical pixels.

Table 3.1: Visual Effects Comparison of Synchronization Experiment

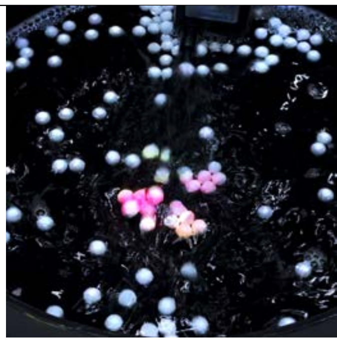
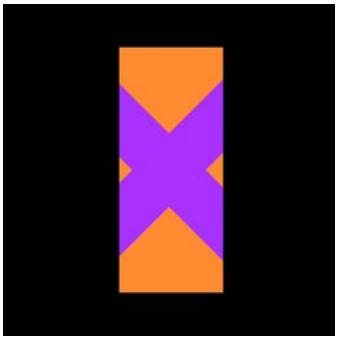
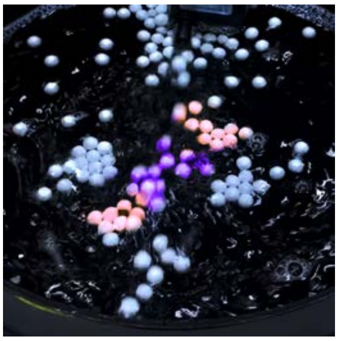
Pin Display Patterns	**Motion Graphics**	**Projection on Pixels**
		
		

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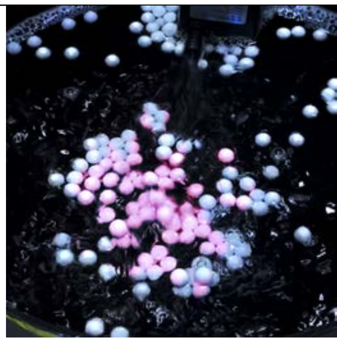
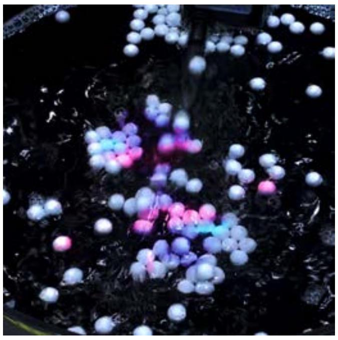
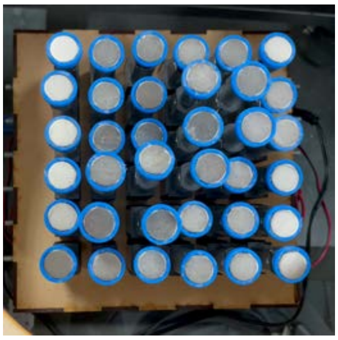
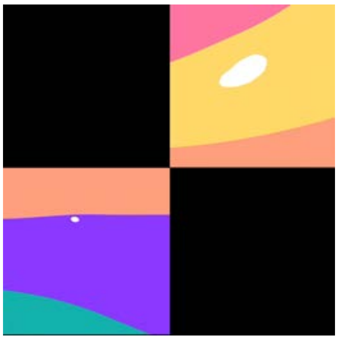
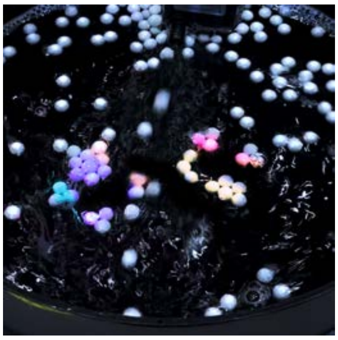
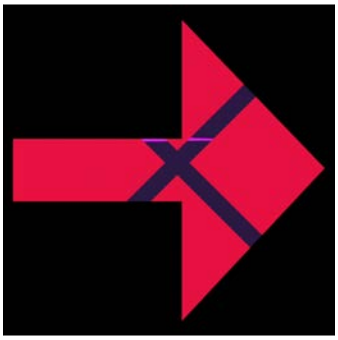
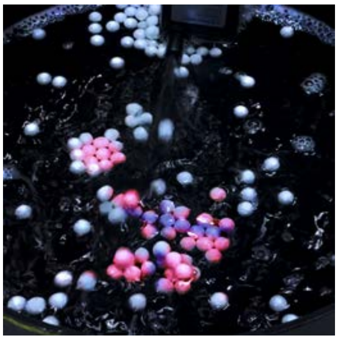
Table 3.1 – continued from previous page

Pin Display Patterns	Motion Graphics	Projection on Pixels
		
		
		
		

3.2.3 Maker Faire Tokyo 2022

Our second prototype was first exhibited as part of the Future Crafts team showcase at the Maker Faire Tokyo 2022[7](Figure:3.11), where we presented the animated motion graphics content designed during the synchronization experiment mentioned in section 3.2.2. However, due to manual control of timing and the bright lighting conditions at the venue, the projection often fell out of sync and didn't have the desired effect.

The prototype attracted a diverse range of visitors, from young children to university instructors and inventors. Particularly captivating for children aged 5-10 was the intriguing movement of the pixels, driven by invisible magnetic forces, indicating its potential educational use in teaching principles of science and physics.

Figure 3.11 Tokyo Maker Faire 2022

7 https://makezine.jp/event/makers-mft2022/m0073/

Despite this, feedback indicated that the resolution and color clarity of the projected visual content was low, making it difficult to decipher the images. The bright venue lighting and mechanical limitations further diminished the impact of the projection. These responses suggest the need for simpler and clearer images in future prototypes to improve visual effectiveness.

We also received a variety of questions and feedback, primarily from university students and instructors. These encompassed a range of topics, such as:

- The potential applications of this device and the specific user experiences it could offer.
- Whether pattern variations could be manipulated and controlled by users, and if this level of interaction could extend to the visual content as well.
- The possibility of transforming the prototype into a full-scale installation, or alternatively, into a practical device for everyday use.
- How the device might be specifically utilized for space performance or stage design, including considerations for large-scale implementations.

3.2.4 KMD Forum 2022

The prototype was also showcased at the KMD Forum 2022[8] (Figure:3.12). For this event, we implemented some enhancements based on previous feedback. We projected a brighter, more vibrant motion graphics video and created a light-blocking barrier around the device using cardboard boxes to boost the visibility of the projected imagery on the pixels.

The movement of the physical pixels and video content was synchronized through programming in Processing, although minor synchronization issues remained.

Visitor feedback from this showcase highlighted several key suggestions and expectations, which included:

- An expressed interest in the manual alteration of shapes through touch or haptic interaction, signifying the potential for tactile engagement in future developments.

8 https://www.keio.ac.jp/en/news/2022/Nov/22/48-133550/

- Expectations for a larger scale and higher resolution of the display, which points towards the need for technological improvements.
- Suggestions for more practical applications in daily life, emphasizing the desire for the device to be not just an installation, but a tool with broader utility.

Figure 3.12 KMD Forum 2022

3.2.5 Problems and New Research Points

Despite the new insights and feedback gained from the showcases discussed in sections 3.2.3 and 3.2.4, as well as our exploration of new approaches to achieving "shape-shifting", we encountered several challenges and identified areas for improvement in our second prototype. These issues primarily included:

- The speed and timing of the pin display's shape-changing patterns, controlled via Arduino programming, failed to perfectly match the changes in the projected video content. Moreover, producing a projection video content that "extremely perfectly" corresponds with the pattern changes of the pin display is a time-consuming process. This disparity often resulted in the patterns formed by the physical pixels being out of sync with the projection video, thus inhibiting the desired visual effect.

- The physical pixels' "shape-changing" forms are influenced by the inherent magnetism of the pixels and the magnets on the pin display. However, due to uneven magnetism strength in the pixels, the pixels sometimes failed to form the desired patterns.

- The movement of the floating pixels is driven by both magnetism and the water flow generated by the pump. Without the water flow, the pixels almost lose their ability to form shape-shifting patterns, which significantly limits their degree of freedom. Moreover, lighting conditions also have a significant impact on the visibility of the projected content.

- The assembly process of the entire device is complex and time-consuming. Each assembly took considerable time to put every part together (projector, water tank, pixels, filling in water, connecting the PC and programming, etc.)

Given these challenges and the feedback from visitors, we identified new research points to address before the final version prototype:

- How can the second prototype evolve into a complete interactive system? What would the user experience, including haptic and tactile feedback, look like?

- How can we make the device's application more convenient and comfortable, particularly in terms of setting up and assembly?

- Can we explore further with materials that can serve as placeholders for digital visual elements and their material interactions? (e.g., physical motion graphics, etc.)

The insights derived and problem analysis conducted guide us in the design of our final prototype.

3.3. New Inspirations

As we concluded the development of our first two prototypes, we found ourselves at a crossroads for our final design—inspiration was elusive. It was during this time that a pivotal intervention occurred. Yuki Akachi, the leader of our display research team, developed a novel display she called the "Poko Sheet Inflatable Display". She shared her concept with us, providing us an opportunity to experiment with this new type of display. This section details our journey with the Poko Sheet—our experimental process, the valuable insights we gathered, and the constructive feedback we received from the KMD Real Project Showcase in April 2023. These experiences invigorated our creative process, guiding us towards a solid design concept for our final prototype.

3.3.1 Poko Sheet Inflatable Display

Yuki Akachi, our team leader at the "display research project team" of Future Crafts, designed an innovative interface named the "Poko Sheet". Taking inspiration from the Japanese word "pokopoko", which mimics the sound of inflating objects, Akachi developed a concept that was geared towards creating a film-based, flexible 3D display [16]. The display is regulated by external forces like air or liquid through the use of an elastomer and an air control device to be a user-interactive, inflatable module [17]. The unique aspect of the Poko Sheet is its capacity to be attached to the screen surface of existing devices, which then brings forth a novel interaction and viewing experience.

The Poko Sheet was tailored to fit the $20cm \times 13cm$ dimensions of the iPad Mini's display area, with Akachi selecting the iPad Mini to project the visual content in this design. The Poko Sheet's structure comprises multiple layers of transparent materials: a base layer of a $20cm \times 13cm$, 0.15mm thick transparent polystyrene sheet; a middle layer made from the translucent 3M 4905 VHB Tape[9] acting as a soft elastomer layer; and a top layer, identical in material and size to the base layer, but featuring a 5cm diameter circular hole and a thin "tunnel" for air inlet, and the circular shape serves as the inflatable shape.

9 `https://www.3m.com/3M/en_US/p/d/b40065643/`

The device assembly was designed to be simple and user-friendly, consisting of the Poko Sheet, a battery pack linked to a DIMINUS DC 6V Mini Air Pump Motor[10], and a soft tube connecting the Poko Sheet with the power and air source (Figure:3.13). To prevent uncontrolled inflation, Akachi cleverly incorporated a control device: a T-shaped tube functioning as an air control switch. This device allows users to regulate the inflatable shape's size and also control its transformation speed by adjusting the air pressure, thereby offering an enriched interactive experience.

In summary, Akachi's Poko Sheet invention introduces a unique means of interaction with digital displays, combining flexibility, tactile feedback, and interactivity into one immersive device.

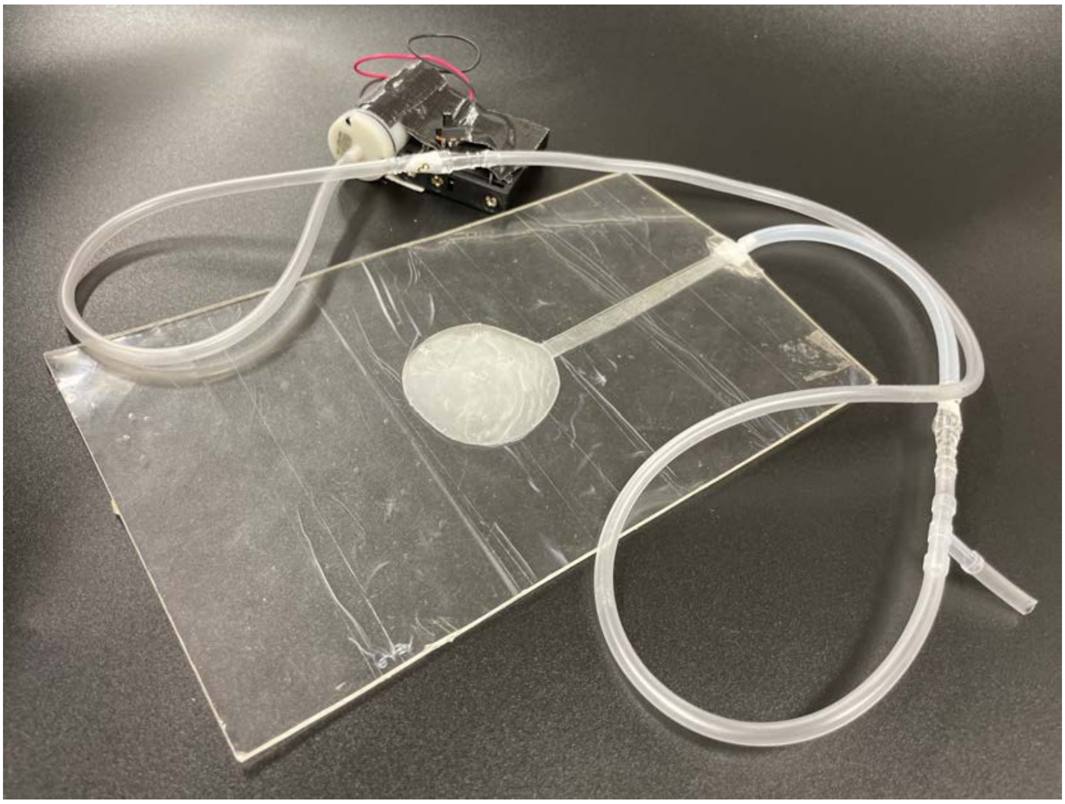


Figure 3.13 Poko Sheet Inflatable Display by Yuki Akachi

10 https://a.co/d/4ETEoSp

Creative Living Lab@SXSW 2023

The initial showcase of Akachi's Poko Sheet Inflatable Display took place at the Creative Living Lab, presented by Nippon TV's R&D Lab and Future Crafts at South by Southwest (SXSW) 2023[11], on March 12th. This showcase was a continuation of Future Crafts's joint research with NTV, themed "Research and Development of Experiential Media Technology that Transmits the Five Senses", which was mentioned in Section 3.1.2. This time, Future Crafts partnered with NTV to present the "Creative Living Lab" project at SXSW 2023, held in Austin, Texas, together proposed innovative living experience ideas and discussed about future living spaces with global innovators[12].

The primary objective of this project was to prototype ideas and experiences that could become a reality in the near future[13]. Akachi's Poko Sheet Inflatable Display was proposed as an innovative display device, intended to enhance interactivity and tactility by attaching a flexible sheet to the screen[14]. This allows visual content to acquire a three-dimensional feel that can be physically touched. Through pump control, the dynamic feel of the content, such as the movement of living objects on the screen, can be amplified, providing a multi-sensory visual experience. It is conceivable that TVs of the future might incorporate this technology to create moving, interactive displays that can transform living spaces.

For the showcase, she used two images-the "fried egg" and the "two cats throwing a ball gif" (Figure:3.14). Feedback about the Poko Sheet was exceedingly positive, gathered from the event's highlight video and reports from NTV personnel. Numerous attendees and participants visited exhibit booth and engaged with the Poko Sheet Inflatable Display. They interacted with it by touching and feeling the texture of the display's inflatable shape while observing the visual content displayed on the tablet. Many of the comments were along the lines of "this

11 `https://www.sxsw.com`

12 `https://lab.ntv.co.jp/topics/2023/03/sxsw2023creative-living-labsxsw2023.html`

13 `https://lab.ntv.co.jp/lab/creative_living/`

14 `https://lab.ntv.co.jp/topics/2023/02/future-life-factoryfuture-crafts-projectssxsw-2023.html`

creation is super interesting".

This inspiring showcase not only served as a validation of Akachi's inventive approach but also greatly encouraged and motivated us in our subsequent design efforts.

(Source: CREATIVE LIVING lab @SXSW2023, by Nippon TV's R&D Lab, 2023[15])

Figure 3.14 Poko Sheet@SXSW2023

15 https://youtu.be/3DcaEhwtGwU

3.3.2 Experiment with Poko Sheet

Akachi guided us in an exploration to determine which visual content would best suit the Poko Sheet display. We agreed that the mascots from our real project - Future Crafts, could perfectly serve this purpose. The mascots, namely "Jella" (magenta), "Petra" (sky blue), "Fabrio" (green), and "Clayton" (yellow) (Figure:3.15), became our test subjects. We generated 3D models of these mascots using Cinema 4D and rendered their front view images against black backgrounds for subsequent testing with the inflated shape of the display (Figure:3.16).

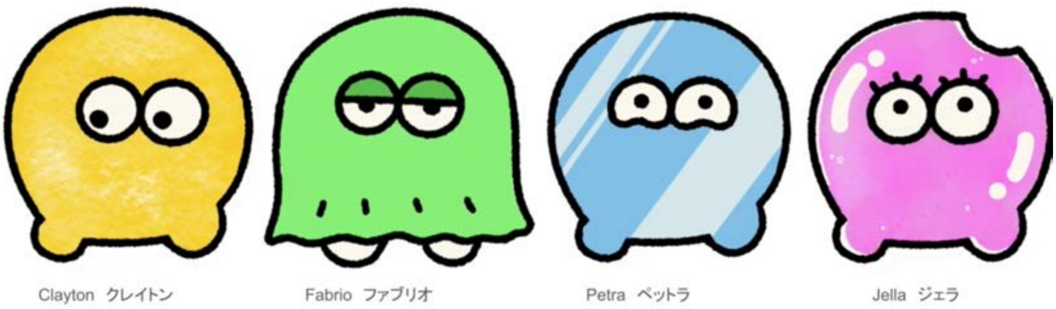


Figure 3.15 Future Crafts Mascots

This experiment, aimed to establish the suitability of visual content for the Poko Sheet display, was also strategically aligned with preparations for the upcoming new student showcase. We envisaged that the novelty and playful visual appeal of the Future Crafts mascots would strike a chord with the fresh audience at the showcase, thus adding another dimension to the practical significance of our experiment.

3.3.3 Feedback from KMD Real Project Showcase 2023.04.06

The Poko Sheet Inflatable Display was exhibited at KMD's Real Project Showcase on April 6th. This event presented an opportunity for the new students from the April 2023 batch at KMD to delve into the specifics of each real project (lab). As representatives of the Future Crafts project, we showcased our experience with the Poko Sheet Inflatable Display.

Figure 3.16 Experiment with Future Crafts Mascots

With an aim to promote our real project, we presented the "Future Crafts mascots" on the Poko Sheet. On the day of the event, Future Crafts booth attracted numerous new and older students alike. They seemed captivated by the prototype, interacting with the inflatable shape and asking many questions, indicating their keen interest.

One particularly thought-provoking comment came from a new student with a background in digital media art. This student suggested that:

- Considering different materials to be layered onto the device, potentially creating varying visual effects such as alterations in resolution, texture, and tone, just like "physical filters".
- Incorporation of physical features that could influence visual effects would add an interesting layer to the prototype.

These insights, in combination with our experimentation with the Poko Sheet and the inspiration drawn from its design, greatly expanded our thinking. They encouraged us to delve deeper into the potential applications of our design concept and significantly influenced the subsequent evolution of our own prototype.

Chapter 4
Implementation and Testing

Having refined our ideas through the development and testing of the initial prototypes and new design inspiration from Poko Sheet as detailed in Chapter 3, we established a new concept for our final design. This evolution was informed by performance testing, exhibition feedback, and visitor interaction, all of which provided valuable insights and ideas. In this chapter, we will delve into the design and development of our final prototype. We'll explore our choice of materials and the process of device construction, elaborate on hardware-specific experiments, and focus on the newly conceptualized user experience and potential interaction design.

4.1. "LiquidLens"

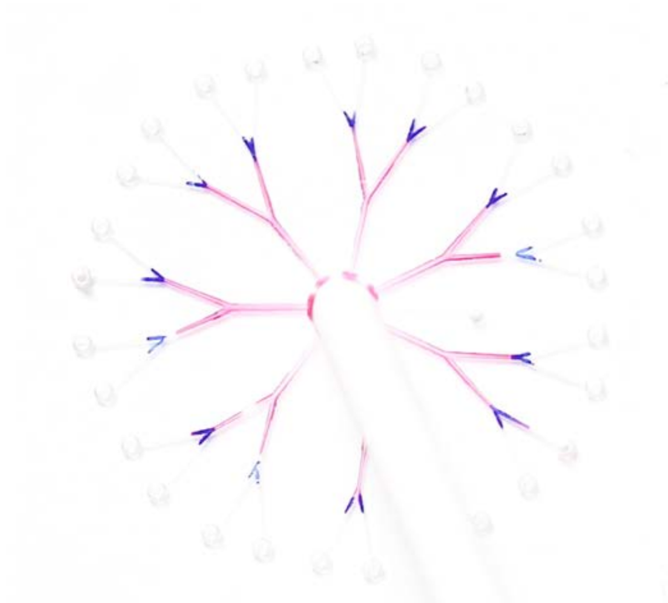
4.1.1 Design Concept

Drawing upon insights derived from our initial two prototypes and experiments with the "Poko Sheet Inflatable Display" developed by Akachi, we identified key challenges such as the assembly process of the device, its constrained degrees of freedom, and the lack of specific user interaction designs. Inspired by these limitations and recognizing new research opportunities, we pivoted towards the development of a liquid-based, shape-shifting projection system for our final prototype.

During our exploration of liquid-based interfaces, the design of the multiple fluidic channels in the "Venous Materials" project by Tangible Media Group[1] (Figure:4.1) greatly inspired our final design. Much like the veins in leaves changing color to

1 `https://tangible.media.mit.edu/project/venous-materials`

indicate the changing seasons or internal conditions, “Venous Materials” utilizes the flow pattern and color change of fluidic channels to inform users about applied motion and physical force. The soft, self-contained mechanism of Venous Materials, functioning as a dynamic display, resonated with our vision for our own design. Their innovative approach to using fluidic interactions for tangible information display offered valuable insights that shaped our final work.



(Source: Venous Materials, by Tangible Media Group, 2020[2])

Figure 4.1 Liquid-Base Interface with Multiple Fludic Channels

Our final design adapts the inflatable elastomer shape from Akachi’s Poko Sheet Inflatable Display to facilitate shape-shifting. In contrast to Akachi’s concept, which centered around attaching a display to screen-based devices, we continued our focus on projection. Thus, the inflatable shape was used as a projection surface.

In addition, feedback on our second prototype, “Floating Pixels”, deemed the “conducting water” aspect intriguing. Coupled with feedback from the Real Project Showcase suggesting the addition of a “physical filter”, these comments

2 https://vimeo.com/420694121

inspired our idea of using liquid within the inflatable shape as a physical filter. This enabled users to fill or inflate the shape with air or water, creating varying visual effects.

Temporarily named “LiquidLens”, this design aims to significantly enhance the user experience by incorporating the properties of the liquid. When the inflatable shape is filled with liquid, it takes on a lens-like appearance, adding depth to the physical-digital interplay and enhancing user interaction (Figure:4.2). This liquid-based system addresses the previous challenges while introducing new possibilities for enhancing interactive experiences.

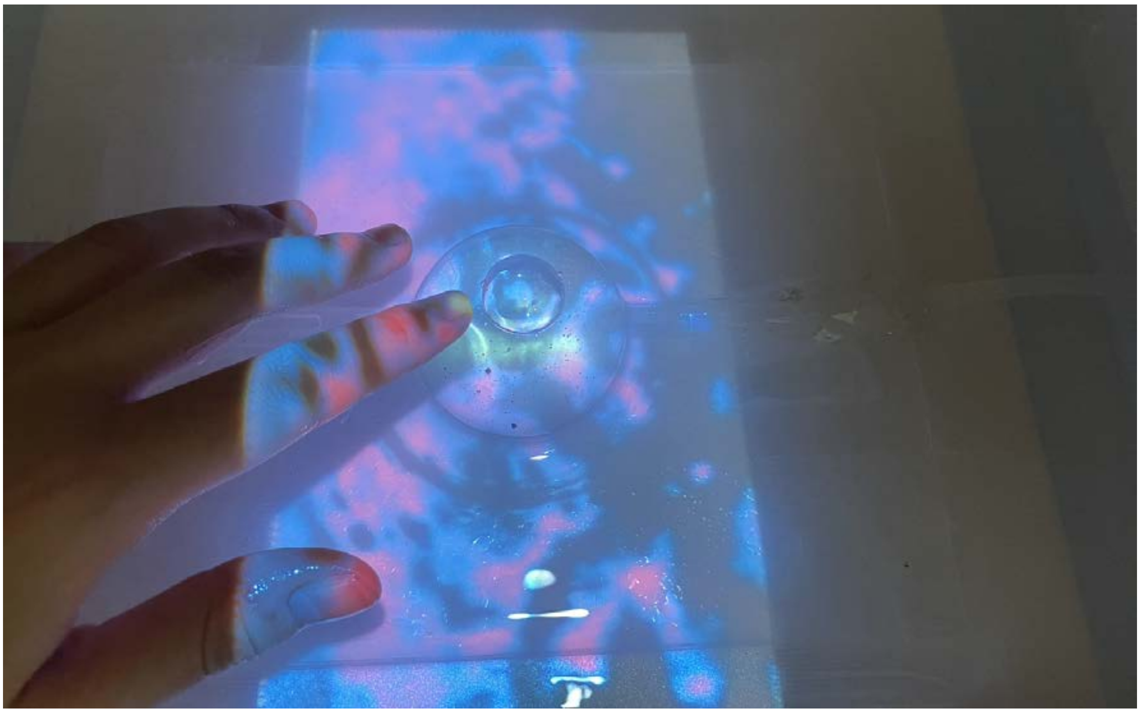


Figure 4.2 “LiquidLens”

4.1.2 Preliminary Experiments

Before crafting our final prototype, we conducted some preliminary experiments (Figure:4.3). One significant experiment involved working with the same material that Akachi employed in her creation, the translucent 3M 4905 VHB Tape. We used this tape to construct small elastomer shapes for our initial tests. To mimic the functionality of the parameter control device in our prototype, we used a 50mL Terumo Syringe[3] to fill these elastomer shapes with air and water. This test allowed us to observe the performance of injection syringe as a controller of both air and water of inflatable shapes.

We also test made our version of the "Poko Sheet" by utilizing two pieces of milk white PP sheets from DAISO[4], cut into dimensions of $20cm \times 15cm$. Like our tests with the elastomer shapes, we experimented with inflating these sheets with both air and water. These initial investigations provided us with valuable insights and formed the groundwork for the development of our final prototype.

Figure 4.3 Preliminary Experiments with Inflatables

3 https://amzn.asia/d/ekssuRw

4 https://jp.daisonet.com/products/4549131311280

4.2. Initial Design of “LiquidLens”

4.2.1 Device Assembly

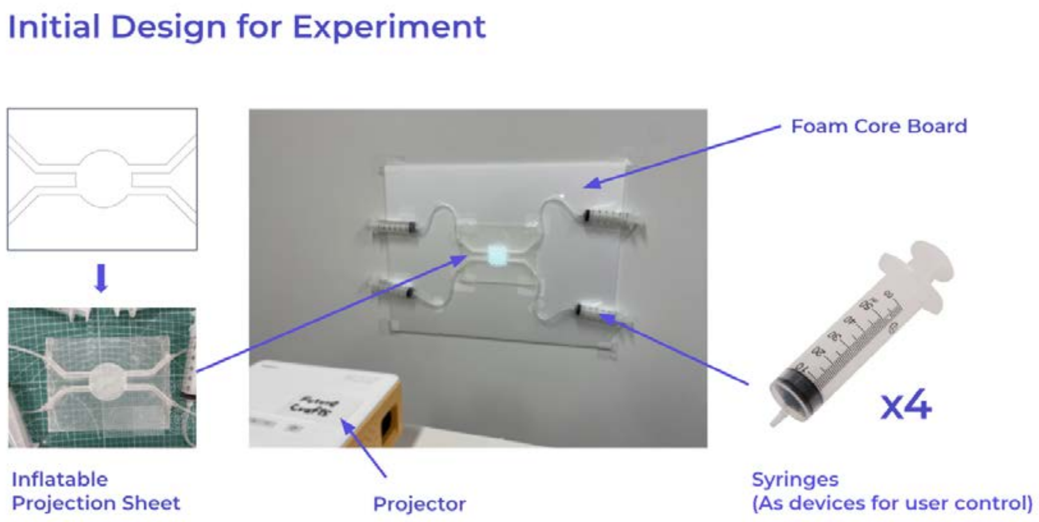


Figure 4.4 Device Assembly of Initial Design

The creation of our initial design of the “LiquidLens” device, required a meticulous assembly process to ensure all the individual components functioned seamlessly together. The overriding objective was to construct an interactive and durable system, one that would withstand repeated user interactions.

The process began with designing a round inflatable shape pattern, featuring inlets on all four sides, using Adobe Illustrator. This pattern was then laser-cut from a 20cm x 15cm PP sheet to create our elastomer display board, effectively forming the “canvas” for our visual content.

Next, we needed to create a system that would allow us to alter the physical state of this display board. For this, we attached four soft tubes to the inflatable shape, with one tube connected to each inlet “tunnel”. These tubes served as the channels through which we could introduce air or water into the system, inflating or deflating the display as required.

To provide user control over this system, we attached four 50mL Terumo syringes to the other ends of the tubes. This setup allowed the inflatable display to be manipulated from all sides, and by multiple users simultaneously, enhancing the interactive nature of the device.

With all the components connected, the final step was to mount the assembled device onto a white foam core board (Figure:4.4). This board served as the projection background, amplifying the visual output while also providing stability to the entire setup.

4.2.2 Hardware Experiments

To ensure the performance and capabilities of this design, we conducted two hardware-specific experiments. The first experiment focused on the inflatable "lens" structure's behavior when inflated and deflated, both with and without water. The second experiment aimed to explore variations in visual effects under different parameters, such as forms, shapes, and types of visual content.

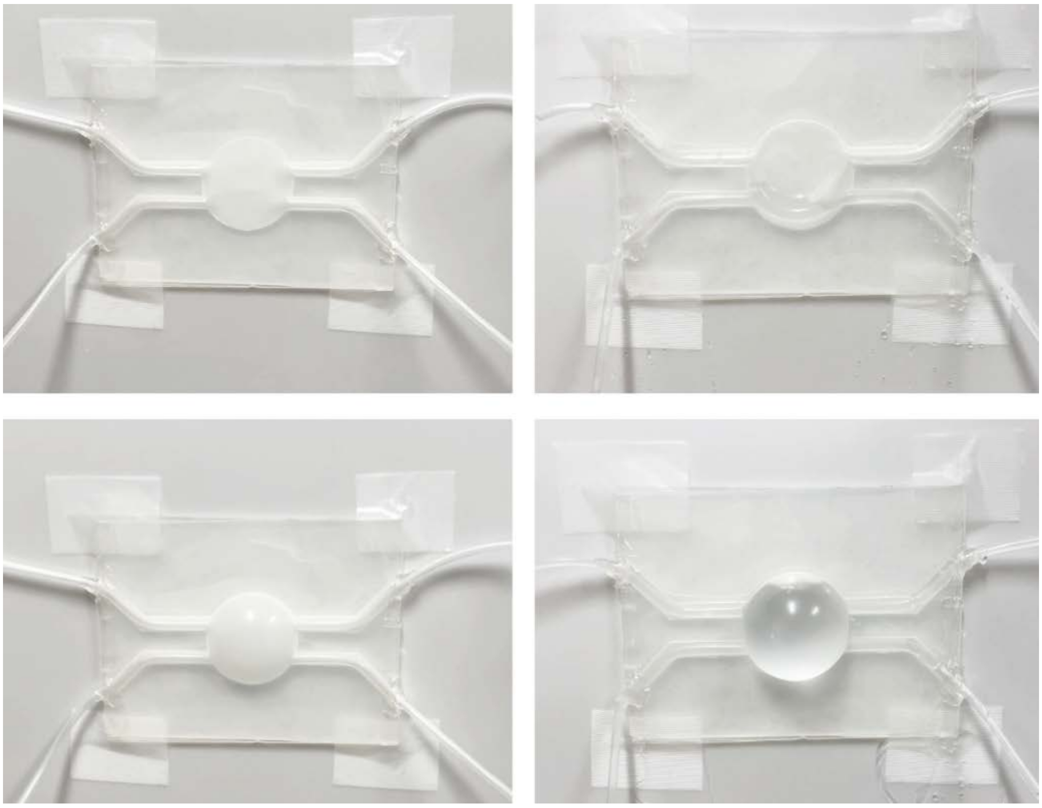


Figure 4.5 Inflatable Part in Different Status

Inflatable LiquidLens

Our first hardware experiment focused on the appearance of the inflatable "lens" structure in different states. We documented how it looked when inflated and deflated, both with and without water (Figure:4.5).

Variations in Visual Effects

Our second hardware experiment explored the variations in visual effects at different parameters.

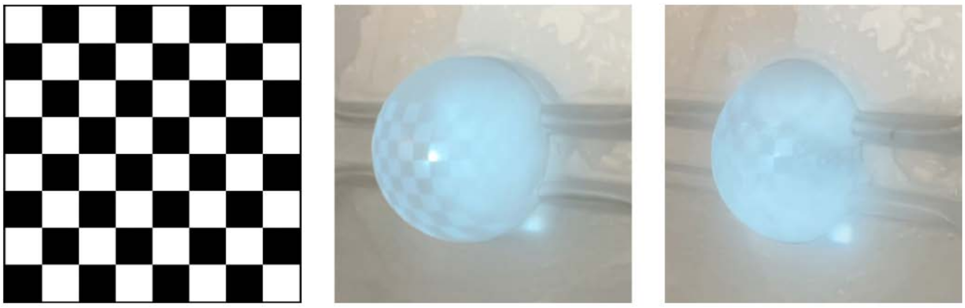


Figure 4.6 Chessboard Pattern Projection Experiment

In the first phase of this experiment, we prepared an image with a chessboard grid pattern (Figure:4.6). We projected this image onto our device in inflated states both with or without water. The visual effects differed in each scenario, displaying various degrees of distortion. Notably, when water was present, the image blurred and distorted in a distinct and interesting way.

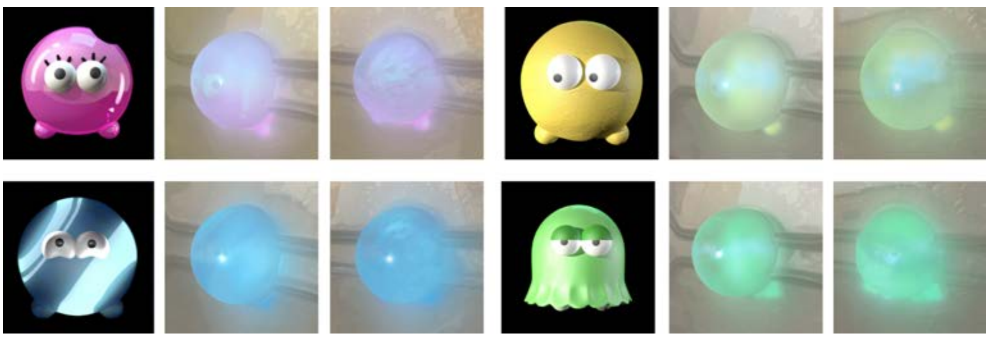


Figure 4.7 Future Crafts Mascots Projection Experiment

In the second phase of the experiment, we investigated the visual effects of different colors and forms using the 3D key visuals of the Future Crafts mascots, as discussed in section 3.3.2. Compared to attaching the inflatable display sheet onto the screen, the projections on the inflatable shapes appeared more vivid, creating the illusion that these endearing mascots were "emerging from the screen". Projections involving water further distorted their features, particularly their eyes, rendering them humorously distorted in a unique way (Figure:4.7).

The final phase of our visual effects experiment explored the impact of various types of visual content, such as motion graphics videos (Figure:4.8). The aim was to examine the possible applications and visual impacts created by the interaction of physical inflatable shapes and digital visual contents.

Figure 4.8 Motion Graphics Projection Experiment with Initial Design

4.2.3 Problems with the Initial Design

Our initial round design for the "LiquidLens" system did present some challenges that required further refinement. One major issue was the complication introduced by having four inlets for inflation. This arrangement made the inflation process unwieldy and less intuitive than we had hoped. Additionally, conducting experiments with water proved difficult due to leakage and straining, making the design less reliable than required.

4.3. Final Design of "LiquidLens"

4.3.1 Device Assembly

Drawing upon the issues encountered in the initial design, we made a series of crucial improvements to develop the final design of our device (Figure:4.9). Firstly, we addressed the leakage issue by placing the display sheet in a tray filled with water. This decision not only solved the problem but also introduced a new form of user interaction — the act of touching the water itself. We also returned to the overhead projection approach used in our earlier prototypes to capitalize on its simplicity and familiarity.

Furthermore, to streamline the inflation process, we reduced the number of inlets from four to two. This simplified design made the device more user-friendly. Lastly, we incorporated T-shaped connectors into our design, improving both stability and functionality.

This improved version marked the device assembly of the final design. These enhancements were pivotal in refining our concept and heightening the overall user experience with our liquid-based shape-shifting projection system, "LiquidLens".

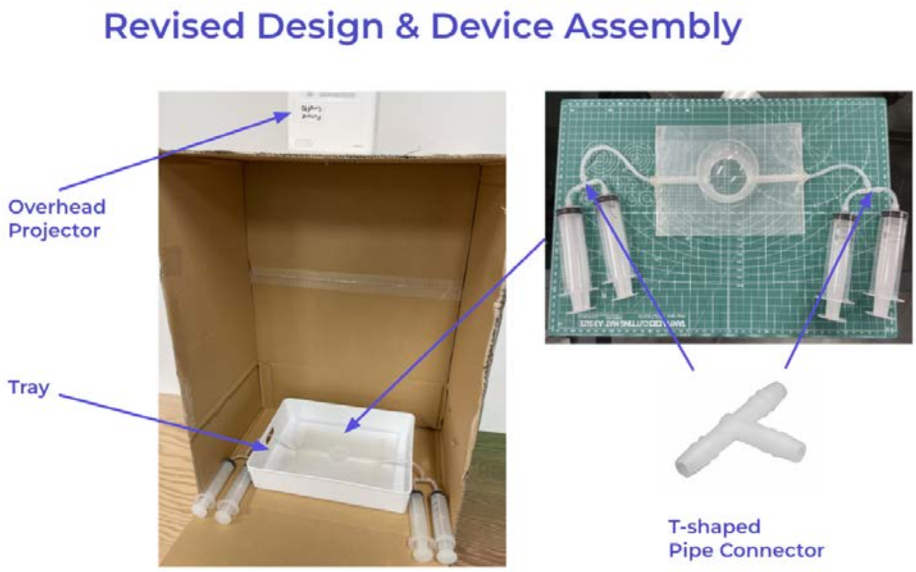


Figure 4.9 Device Assembly of Final Design

4.3.2 Hardware Experiments

In our quest to validate the performance and capabilities of our final design, we undertook three hardware-specific experiments. Much like the previous trial in section 4.2.2, our first experiment was dedicated to examining the behavior of the inflatable "lens" structure when filled with water in the tray.

Our second experiment, on the other hand, aimed to explore variations in visual effects under different parameters. However, this time around, our focus was specifically oriented towards altering the properties of the liquid used within the inflatable shape.

And our third experiment, a new addition to our tests, explored the visual impact of integrating physical materials into the liquid. The aim was to investigate how these materials could serve as an additional layer of a "physical filter" to further influence and enrich the visual output.

Inflatable LiquidLens in the Tray

The first experiment aimed to examine the shape-shifting performance and appearance of the inflatable "lens" structure when filled with water in the tray. To assess the interactive quality, we physically interacted with the inflatable shape by touching it, studying the tactile feedback and its influence on the system's behavior (Figure:4.10).

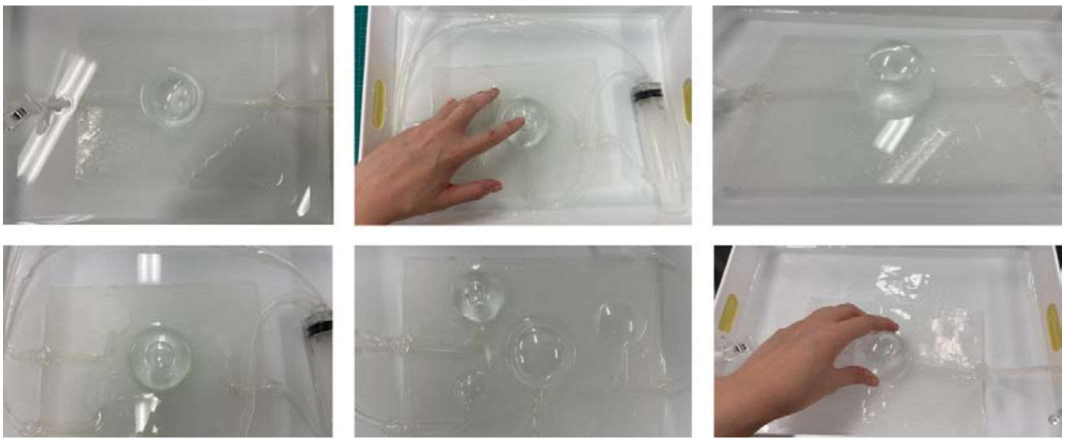


Figure 4.10 Inflatable Shape in the Tray

Variations in Visual Effects at Different Parameters

The second experiment aimed to explore variations in visual effects at different parameters, specifically focusing on the transparency of the liquid used within the inflatable “lens” structure. The experimental method involved the addition of white pigments to the water to create varying levels of transparency. We conducted this experiment using four different parameters: 0% (clear liquid), 30% transparency, 60% transparency, and 100% (completely white)(Figure:4.11).

Figure 4.11 White Pigment in Different Levels

As we increased the transparency level, we observed a corresponding improvement in the clarity of the projected image (Table: 4.1). This led to the realization that the level of transparency directly impacts the clarity and effectiveness of the projection. Through these tests, we sought to identify the optimal transparency level to achieve the desired visual effect.

Table 4.1: Visual Effects Comparison at Different Transparency Levels

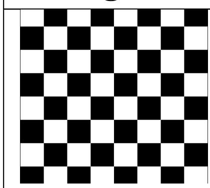
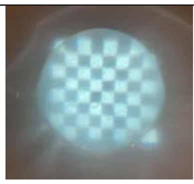
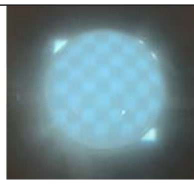
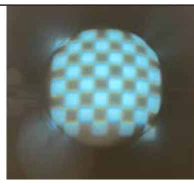
Original	**0%**	**30%**	**60%**	**100%**
				

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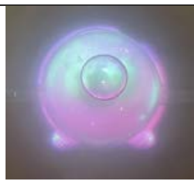
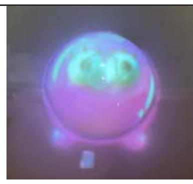
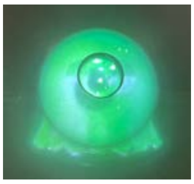
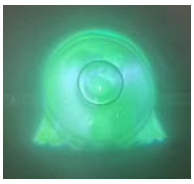
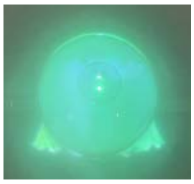
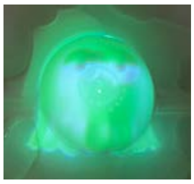
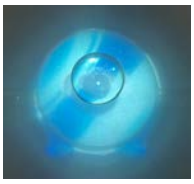
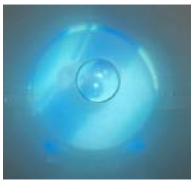
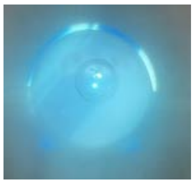
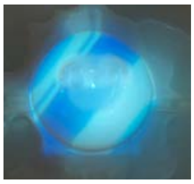
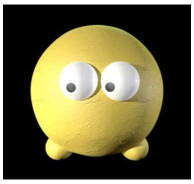
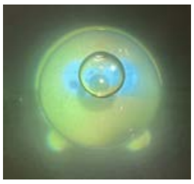
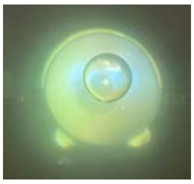
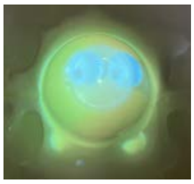
Table 4.1 – continued from previous page

Original	0%	30%	60%	100%
				
				
				
				

Variations in Visual Effects with Different Physical Materials

In our third experiment, we ventured to investigate the visual effects created by different “physical filters” within the inflatable shape. This experiment entailed the use of materials with reflective properties, such as reflective powder and glitter. We filled the inflatable shape with these materials to observe their effect on the visual output (Figure:4.12).

Figure 4.12 Experiment with Different Physical Materials

The interaction between these physical materials and the projection produced a attractive and dynamic visual effect. The physical materials added a layer of physical "texture" to the visual content (Table: 4.2), further enhancing the immersive experience offered by our device. Through this experiment, we established the potential of incorporating various physical materials as "filters" within our design.

Table 4.2: Visual Effects Comparison with Different Materials

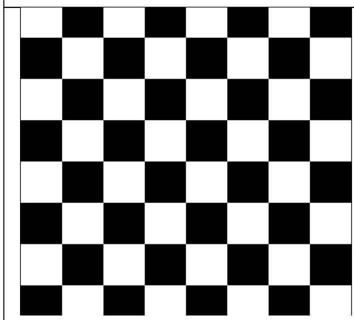
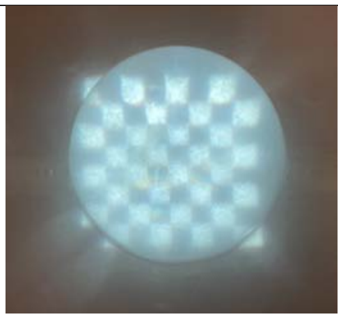
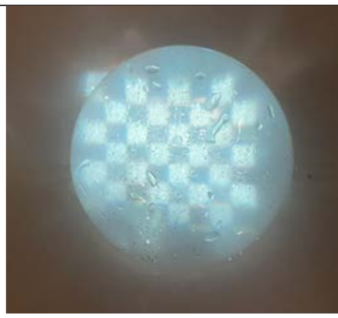
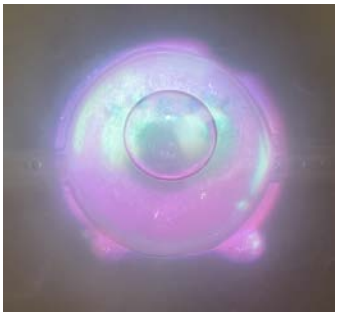
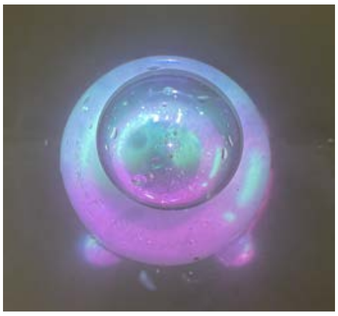
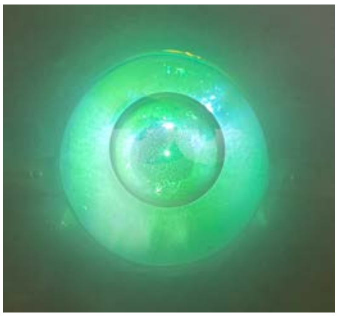
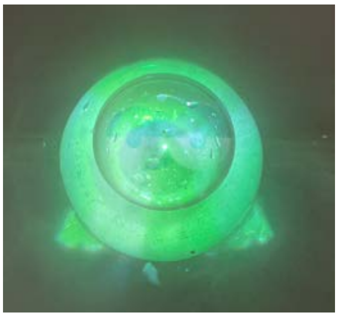
Original	**Reflective Powder**	**Glitter**
		
		
		

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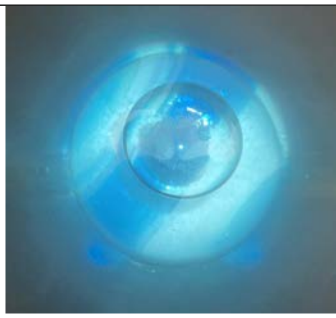
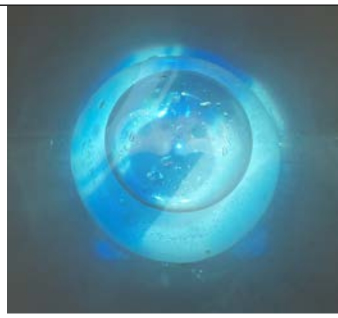
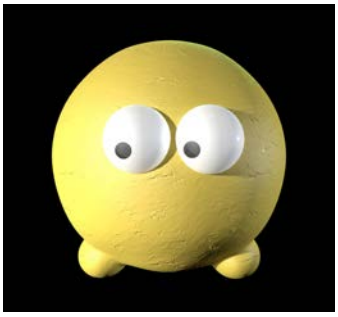
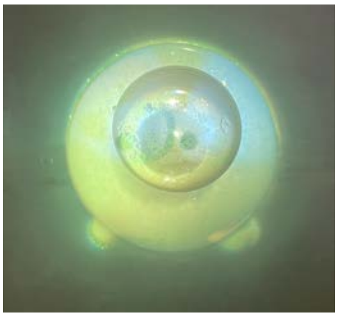
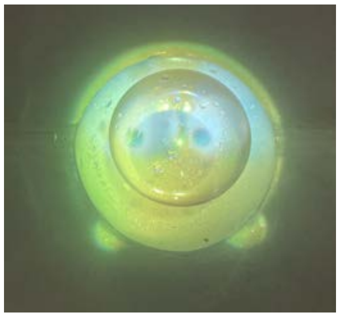
Table 4.2 – continued from previous page

Original	Reflective Powder	Glitter
		
		

Motion Graphics Projection Experiment

We conducted an additional projection experiment that focused on the interaction of our final version design with dynamic digital visual content (Figure:4.13). We utilized the same motion graphics video as referenced in section 4.2.2, intending to examine how our design could accommodate and enhance the projection of moving digital imagery.

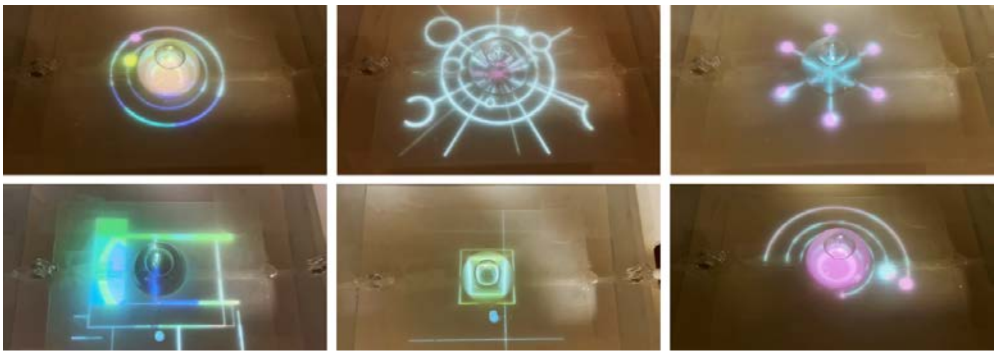


Figure 4.13 Motion Graphics Projection Experiment with Final Design

Chapter 5
Evaluation

5.1. User Study

Our final prototype, the "LiquidLens", recently underwent user testing in a projection experiment at KMD. The purpose of this experiment was to gather valuable feedback and gain fresh perspectives from diverse participants with different backgrounds. This feedback will help us identify areas for improvement in the prototype and concept design.

Figure 5.1 Projection Experiment at KMD

5.1.1 Projection Experiment in KMD

In an effort to explore additional potential user scenarios for our final prototype's design concept, we recently conducted a projection experiment at KMD. The workshop's objective was for the participants to think about and prepare visual content that they thought would match this design concept and generate a significant impact on visual effects.

Around 10 students from various backgrounds at KMD were invited to the experiment to participate in a user test. Our goal was to gather insights and inspiration from diverse perspectives. A majority of the participants had backgrounds in art and design, and they provided a lot of valuable feedback and insight via a survey we conducted following the user test.

The survey included the following four questions:

1. What do you find interesting or positive about this design? What do you see as areas of improvement or limitations in this design?

2. What type of visual-based digital media content do you think would suit this design?

3. In what other scenarios/applications could this design potentially be applied to (especially on a larger scale or in a different setting)?

4. What features do you think could be added to this type of design to enhance it or make it more interactive?

Furthermore, we selected four outstanding user test results and categorized them into two groups based on their characteristics and related fields: "Interactive Daily Life Journal" and "Interactive Artistic Expression". Two results were chosen for each category. The following subsections will detail our records of these three categories, including the specific visual content prepared by the participants, the visual effects observed through this prototype, and the insights and potential applications suggested by the participants in response to the survey questions.

Interactive Daily Life Journal

The first category we defined is "Interactive Daily Life Journal". This category refers to participants who used visual content from their everyday lives to document their experiences and explored possible approaches to record their daily lives in a more interactive way through this prototype.

Figure 5.2 Projection Experiment with Participant No.1

Participant No.1 has a hobby for sketching significant events in her life with colored pencils. She prepared a circular drawing that narrates a memorable day where she attended an interview for a part-time job. Inflating the shape to varying sizes, physically interacting with it, and viewing her sketch through the distorted lens of the liquid-filled shape with glitter as a "physical filter" seemed to bring the memory of that day to life in a vivid and tactile way. She shared the following reactions and insights:

- The design made her flat drawings seem more three-dimensional.
- Images or drawings with depth or perspective that are difficult to convey on a flat screen may be suitable for this design concept. It could be also applied in children's picture books to enhance interaction.
- Beyond the circular shape, it would be more interactive if it could transform into other shapes, like an expanding heart.
- By manipulating the properties of the liquid, such as color and viscosity, this design concept could allow for customization and adaptation in various fields, from entertainment to therapeutic applications.

Participant No.2 is an avid traveler who enjoys taking selfies at various destinations as a record of his travel experiences. He prepared a selfie taken during a trip to Kyoto the last summer. The inflatable shape neatly fitted over his face in the photo, creating an interesting visual effect. He remarked that it felt like he was wearing a “spaceman’s transparent helmet”, sparking thoughts about space travel. He also offered these reactions and insights:

- The inflatable part creates a more immersive sensory experience by making the visual contents appear three-dimensional effect on the flat screen.
- The hands-on adjustment of inflation and liquid properties adds a playful element, turning passive viewing into an engaging, creative experience.
- The design may suit photos with a focal point in the middle, and comedic content might also utilize this design to enhance the “visual comedy effect”.
- Allowing users to control more parameters would enhance the interactivity and offer more flexibility to achieve the desired visual effects.

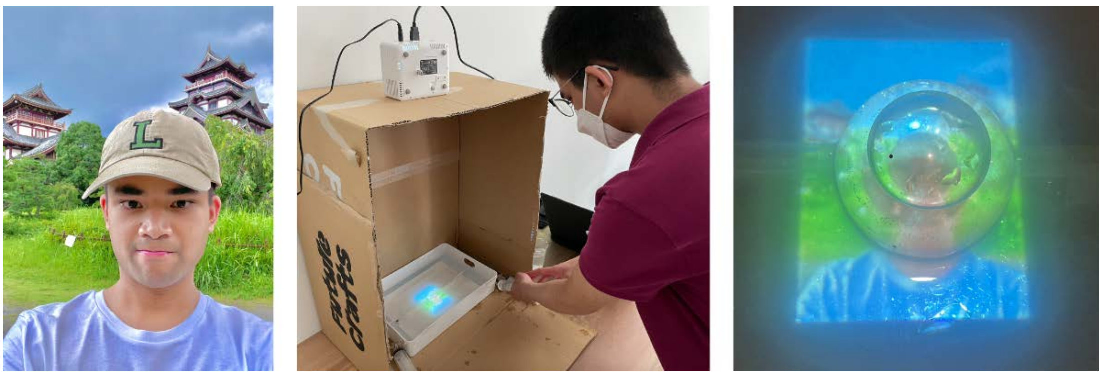


Figure 5.3 Projection Experiment with Participant No.2

From these two user tests, we gained valuable insight and fresh inspiration on how this design concept could enhance interaction, documenting our daily life experiences from unique perspectives. The use of water in the prototype, in particular, introduced a fluid and dynamic aspect, adding an extra layer of depth and tangibility to these experiences, making our everyday life more entertaining and engaging.

Interactive Artistic Expression

The second category we defined is "Interactive Artistic Expression". This category consists of participants who used their own artwork or designs as visual content and explored possible methods of creatively expressing their artwork through this prototype.

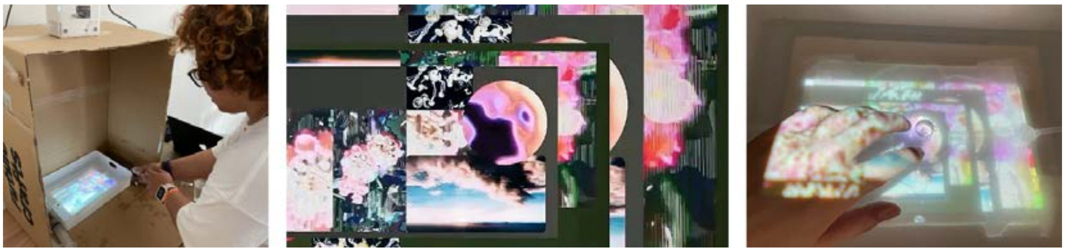


Figure 5.4 Projection Experiment with Participant No.3

Participant No.3, a visual designer well-versed in creating innovative Instagram posts and stories, provided an Instagram story video as her visual content. This video showcases vibrant glitch effects with overlaid geometric shapes. The introduction of the inflatable shape filled with liquid and reflective materials added a strikingly tangible sense of dynamism and amplified the visual impact, prompting a surge in her creative thinking.

Her reactions and insights were as follows:

- This design could be well-suited to interactive designs/artworks, such as collages or paintings, and even games.
- The interactivity with the visuals behind the inflatable shape coupled with the liquid makes it a compelling piece of interactive artwork.
- It might be worth considering adding different sensors, such as capacitive or pressure sensors.
- Creating a range of movements with the inflatable shape could make the experience more vivid and dynamic.
- Engaging with dynamic artwork is fascinating because it gives viewers a unique way to form a connection and find relevance with the art.

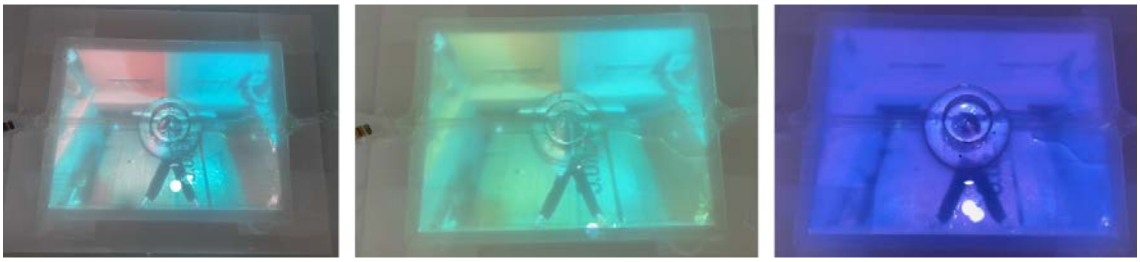


Figure 5.5 Projection Experiment with Participant No.4

Participant No.4 is a jazz-pop dancer who often records videos of her choreographies. Her visual content was a video showcasing her latest jazz-pop dance routine performed in a studio. The striking contrast created by the flickering lights in the dim environment, along with the perfect alignment of the inflatable shape with her body in the video, elevated the overall visual impact to new heights. By adjusting the size of the inflatable shape in sync with her dance movements, she was able to generate a stunning visual effect. This not only validated the quality of her choreography but also sparked new ideas for future dance routines.

She offered the following reactions and insights:

- The design introduces an engaging and dynamic perspective to her dance video. The fluidity of the liquid enhances the aesthetics of movement.
- It would be interesting if the design, leveraging the adaptive nature of liquids, could modify its appearance according to the music or display content.
- While motion pictures seem more suitable and impactful, static images that provide different visual effects from various angles due to the liquid's refractive properties could also be intriguing.
- The design would be more engaging if the visual content could change in response to touch or other forms of interactive communication with individuals, using the liquid as a dynamic canvas.
- Including realistic sounds that match the liquid movements could add another layer of immersion.

Our projection experiment using the "LiquidLens" prototype provided us with significant insights into the potential of our design across various fields. The incorporation of liquid added a dynamic quality, enabling multi-dimensional artistic expression beyond flat media. Feedback from participants with diverse backgrounds led to innovation and highlighted areas for enhancement, emphasizing the value of user-centric design. Through material exploration, we found that the inflatable interface with liquid provided efficient performance for shape-shifting and interaction, inspiring new possibilities in interactive art and design.

5.2. Improvement Points

Despite the constructive insights and positive feedback, we noted several challenges during the prototype testing and user evaluation phases. Areas for improvement include:

- The issue of bubbles forming when inflating with liquid has affected the quality of projection and viewing experience. These bubbles create obstructions and distortions in the projected images, lessening the clarity and overall quality. Exploring methods to prevent bubble formation, changing the stickiness of the liquid by using gel, or using materials with better refraction properties could enhance this aspect.
- The current design proved challenging to make the inflatable part movable, limiting the potential for dynamic interactions. As a result, synchronizing movements created by adjusting the size of the inflatable part with the visual content became difficult. Future designs could include a more flexible or automated mechanism for inflating and deflating the component or even consider multiple cells to drastically change the interaction dynamics.
- The current shape of the inflatable part is a simple circle. For more versatility in the visual effects, future iterations could incorporate a variety of shape forms or even allow users to adjust the shape of the inflatable part, thereby achieving various forms of shape-shifting. The shape of the cell could also be revised; for instance, an air pump-like shape could allow for a flat top surface.

- It's necessary to add more adjustable parameters and features (e.g., shapeforms, colors, sound-based features, etc.) to amplify interactivity.
- With regards to water-related limitations, the system's water resistance needs improvement as we observed water leakage from the prototypes during experiments. A more waterproof design would allow for more reliable and varied applications.
- Using different colored liquids, rather than solely transparent or white ones, inside the inflatable part could offer a range of interesting visual effects and deepen the immersive experience.
- Lastly, both the user interaction "parameter controller" and the overall device need to be refined and integrated more effectively to function as a cohesive system. Considering the possibility of a single display cell or multiple cells could bring about a significant transformation in the overall device functioning.

We acknowledge that our current prototype has its limitations, particularly in terms of liquid usage and design. However, the feedback and insights gleaned from showcases and workshops offer various avenues for improvements and innovation. By addressing these points, we aim to design a more interactive and immersive shape-shifting projection interface in future iterations, one that fully exploits the dynamic and fluid properties of liquid to provide a truly unique user experience. Alongside these enhancements, we are also aiming to improve the whole system's performance and functionality, ensuring a seamless and effective utilization of the technology in various applications.

5.3. Evaluation Comparison

We developed two prototypes, "Floating Pixels" and "LiquidLens", both involving liquid. Through prototyping, experimentation, and feedback from user studies and exhibitions, we assessed their performance and unique characteristics. The evaluation comparison listed below summarizes our findings, revealing distinct features and insights that informed our final design direction.

Table 5.1 Comparison between Floating Pixels and LiquidLens

Aspect	Floating Pixel	LiquidLens
Interactivity	Provided basic interaction through floating elements.	Enhanced interaction by allowing users to manipulate the shape and orientation of the display.
Visual Quality	Visual output dependent on fixed pixel arrangements via Arduino programming.	Improved visual quality with customizable views and flexible display structures.
User Control	Limited user control with predetermined pixel movements.	Enhanced user control with adjustable volume and pressure of the liquid.
Innovation	Novel use of floating elements for a display system.	Innovated by integrating tactile, immersive experiences in a digital display.

The evaluation of the "Floating Pixels" (2nd Prototype) and "LiquidLens" (Final Design) culminated in significant insights into the effectiveness of both designs. "LiquidLens" demonstrated a more optimal performance in terms of enhanced interactivity, visual quality, and user control. However, it also revealed certain shortcomings such as the issue of bubbles affecting the projection quality and water leakage. These unsuitable aspects have pointed the way to specific areas for improvement. Meanwhile, the "Floating Pixels" provided a novel approach but was limited in user control and visual output. Through these comparisons, the foundation has been laid for future design development. It's necessary to focus on addressing the identified challenges, experimenting with different liquid properties, and incorporating user feedback to enhance the entire system's functionality and achieve a truly innovative and immersive projection interface.

Chapter 6
Conclusion and Future Works

6.1. Conclusion

Our research, centered around the innovative fusion of physical and digital experiences, led us to the creation of the “LiquidLens” Display. Through this work, we’ve seen firsthand how integrating these distinct realms can fundamentally transform the dynamics of user interaction with digital content.

The novelty of our research lies in its potential to shift perceptions of digital content, transitioning it from a purely visual medium to one that is tactile and immersive. The “LiquidLens” projection interface isn’t just a static interface, it is an interface that morphs and interacts with the user in ways that traditional displays simply cannot match. By bridging the physical and digital worlds, it offers a unique, multi-sensory interaction that challenges the conventional definition of “display”.

The process of designing and refining our concept was informed by a comprehensive review of related works. This backdrop helped us understand our research in a broader context. As we progressed from exploring diverse material options to developing the interactive mechanism, we honed the features of our prototype to optimize the user experience.

The utilization of liquids, specifically liquid, in our design became a distinguishing factor. The inherent fluidity and malleability of liquid brought life to our “LiquidLens” Display, offering an intuitive way for users to reshape and reorient their viewing experiences. By altering the volume and pressure of the water inside the inflatable shape, users could tailor their interactions to suit their personal preferences or requirements.

User testing conducted during a projection experiment at KMD revealed valuable insights from users’ perspectives. This not only affirmed the viability of our concept in various fields like art, design, and everyday life documentation, but also shed light on opportunities for improvement.

Despite the progress made, we understand that our journey is far from over. The insights from the user tests, coupled with identified challenges, open avenues for further exploration. Aspects such as enhancing visual clarity, increasing the adaptability of the inflatable shape, and providing greater user control over parameters are on our road map for future iterations.

In conclusion, our research has demonstrated the potential and versatility of integrating physical attributes into a digital display, leading to more engaging and immersive user experiences. It encourages us to continue pushing boundaries, exploring new materials and technologies, and rethinking the conventional. As we move forward, we are confident that our efforts will contribute significantly to shaping the future landscape of experiential media technology.

6.2. Future Works

Moving forward, there is huge potential for the evolution and application of our research. The primary focus for our future work would be enhancing interaction through the five senses, pushing the boundaries of immersive experiences.

- **Multi-Sensory Experiences**: An immediate direction would be to incorporate other sensory experiences into our design, inspired by studies that employed touch input for eyes-free menu choices and responsive auditory feedback [18]. By integrating auditory and olfactory elements into our prototype, we could provide a more immersive multi-sensory experience. Imagine a user being able to not just see and touch but also hear and smell the digital content, greatly enriching the interaction.

- **Material and Texture Mimicry**: Informed by studies that explored structured tactile signals for displaying information without visual cues [19], a key area of focus would be enhancing the tactile experience. Using advanced materials or incorporating haptic feedback could enable our prototype to mimic the texture of objects in the digital content. This would allow users to "feel" the digital content, further blurring the line between the physical and digital worlds.

- **Large Scale Applications**: As suggested by research on morphological interfaces [20], the potential applications of our prototype extend beyond individual use. On a larger scale, it could be used in performance stages or exhibitions to provide a unique, interactive viewing experience. For instance, performance artists could incorporate our display into their act, creating a novel form of audience engagement. Alternatively, museums or art galleries could use our display to allow visitors to interact with digital exhibits in an immersive way.

- **Expanding Form Factors**: Although the current design features a circular inflatable shape, future iterations could experiment with various shapes and forms. The flexible nature of our liquid-based interface makes it well suited for this expansion. Different liquid volumes or viscosities could result in different shapes and forms, broadening possibilities for creative expression and providing users greater flexibility to customize their interactions with the display.

In conclusion, the future work on our research aims to broaden the horizons of digital interaction, paving the way for more enriched, immersive, and personalized experiences. With continuous innovation, we hope to redefine the boundaries of experiential media technology.

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Appendices

A. Arduino Code for Pin Display

```
int pattern[6][36] = {

    0, 0, 0, 0, 0, 0,
    0, 0, 0, 0, 0, 0,
    0, 0, 1, 1, 0, 0,
    0, 0, 1, 1, 0, 0,
    0, 0, 0, 0, 0, 0,
    0, 0, 0, 0, 0, 0,
  }{
    0, 0, 0, 0, 0, 0,
    0, 0, 1, 1, 0, 0,
    0, 0, 1, 1, 0, 0,
    0, 0, 1, 1, 0, 0,
    0, 0, 1, 1, 0, 0,
    0, 0, 0, 0, 0, 0,
  },{
    0, 0, 0, 0, 0, 0,
    0, 1, 1, 1, 1, 0,
    0, 1, 1, 1, 1, 0,
    0, 1, 1, 1, 1, 0,
    0, 1, 1, 1, 1, 0,
    0, 0, 0, 0, 0, 0,
  },{
    0, 0, 0, 0, 0, 0,
    0, 1, 1, 0, 0, 0,
    0, 1, 1, 0, 0, 0,
    0, 0, 0, 1, 1, 0,
```

```
    0, 0, 0, 1, 1, 0,
    0, 0, 0, 0, 0, 0,
  },{
    0, 0, 0, 0, 0, 0,
    0, 0, 0, 1, 1, 0,
    0, 0, 0, 1, 1, 0,
    0, 1, 1, 0, 0, 0,
    0, 1, 1, 0, 0, 0,
    0, 0, 0, 0, 0, 0,
  },{
    0, 0, 0, 0, 0, 0,
    0, 0, 0, 1, 0, 0,
    0, 0, 0, 1, 1, 0,
    1, 1, 1, 1, 1, 1,
    0, 0, 0, 1, 1, 0,
    0, 0, 0, 1, 0, 0,
  },
;

int servopin[36][2] =
{ {2, 3}, //JP1
  {4, 5}, //JP2
  {6, 7}, //JP3
  {8, 9}, //JP4
  {10, 11}, //JP5
  {12, 13}, //JP6
  {22, 24}, //JP7
  {26, 28}, //JP8
  {30, 32}, //JP9
  {34, 36}, //JP10
  {40, 38}, //JP11
  {42, 44}, //JP12
  {46, 48}, //JP13
  {50, 52}, //JP14
  {23, 25}, //JP15
  {27, 29}, //JP16
```

```
  {31, 33}, //JP17
  {35, 37}, //JP18
  {39, 41}, //JP19
  {43, 45}, //JP20
  {47, 49}, //JP21
  {51, 0}, //51-NULL: JP22 forget..
  {53, 54}, //JP23
  {55, 56}, //JP24
  {57, 58}, //JP25
  {59, 60}, //JP26
  {61, 62}, //JP27
  {63, 64}, //JP28
  {65, 66}, //JP29
  {67, 68}, //JP30
  {69, 20}, //JP31
  {21, 15}, //JP32
  {14, 17}, //JP33
  {16, 19}, //JP34
  {18, 1},//JP35
  {0, 0} //JP36
};//NULL forgot

void setup() {

  for (int i = 0; i < 36; i++) {
    motor_set(servo_pin[i][0], servo_pin[i][1]);
  }
  //delay(5000);
}

void loop() {

for(int n = 0;n<9;n++){

    for (int i = 0; i < 36; i++) {
    if (pattern[n][i] == 1) {
```

```
      motor_move(servo_pin[i][0], servo_pin[i][1], 1);
    } else {
      motor_move(servo_pin[i][0], servo_pin[i][1], 0);
    }
  }
  delay(2000);
}
}
void re() {
  for (int i = 0; i < 36; i++) {
    motor_move(servo_pin[i][0], servo_pin[i][1], 0);
  }
  delay(3000);
}
```

B. Arduino Code for Pin Display's Motor SetUp

```
void motor_set(int in1, int in2) {
  pinMode(in1, OUTPUT); //U1INA1
  pinMode(in2, OUTPUT); //U1INA2
}

void motor_move(int in1, int in2, int dir) {
  if (dir == 0) {
    digitalWrite(in1, HIGH);
    digitalWrite(in2, LOW);
  } else if (dir == 1) {
    digitalWrite(in1, LOW);
    digitalWrite(in2, HIGH);
  }
}
```