Topplr

An emotive interface
for music streaming services.

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1. INTRODUCTION

"Humans have evolved a heightened ability to sense and manipulate the physical world, yet the GUI based on intangible pixels takes little advantage of this capacity" – (Ishii et al., 2012)

As the era of ubiquitous computing unfolds, many have explored divergent approaches to support human-computer interactions, resulting in various types of interfaces but actuated interfaces have not yet been widely introduced in our everyday life.

As humans are so much capable of sensing and manipulating matters in the physical world, but this has not been fully leveraged. Recent research has shifted to explore different methods of turning digital bits into graspable objects, allowing physical objects to breakthrough its static form and turning the physical properties interact-able.

This matures the research on shape-changing/actuated interfaces, contributing a wide range of peer-reviewed works and suggesting the benefits/purposes of shape changes (Alexander et al., 2018) . However, such tangibly actuated designs haven't been widely applied in our everyday life. Most of the currently marketed products are still leveraging the audio and visual output as communicating modalities.

The loss of tangibility of interacting with our surrounding products and services could result in disconnected interactions from the physical world, impoverished user experience and increased risks of user alienation from the physical world (Angelini et al., 2018). This instigates me to think about the value of tangible interactions in a home environment. And this is what this project is about. In the past year, I have explored what the tangible outputs be like and how to instigate more intriguing designs. This resulted in *Topplr* and ESPBoost, an emotive interface and a design toolkit respectively.

In this report, I describe my master's graduation project conducted at the Department of Industrial Design of Eindhoven University of Technology.

This report is documented in chronological order, guiding the reader through an interactive process of the Research through Design (RtD) approach (Zimmerman et al., 2007) of the project. Each iteration instigated new insights and knowledge, contributing to the final design. The project initiated from an infant idea named *Topplr* from an elective at my M1.2 and my enthusiasm for *Peripheral Interaction (Bakker et al., 2015)* has encouraged me to further develop the concept and explore new design possibilities.

The first chapter of this report introduces the first phase mainly conducted during the M2.1 phase, investigating peer-viewed designs, exploring and framing the design objectives, which turned out defining the main theme of this project as *designing tangible outputs of everyday objects*. Next to that, more in depth literature reviews regarding interaction theories were conducted to frame explicit design rationale.

The second chapter of this report investigates the value of the tangible output of *Topplr* (at the early stage) and given the difficulties in rapidly prototyping tangible output extensively as well as the Covid-19 policy, explorations were made within a 3D rendering platform followed by a preliminary evaluation of the perceived emotions. In parallel, this study evaluates how my experiences as a tangible interaction practitioner could contribute to their prototyping process.

The third chapter of this report describes two final designs Topplr and ESPBoost respectively, which were proposed through synthesized reflections from the previous activities. This chapter also explicitly introduces the usage and technical specification of the design; the last two-chapter discus the value of the design from three main aspects, limitations and future implementations, which leads to the final conclusion.

Throughout the project, required deliverables and documents have been archived on publicly accessible GitHub repository as evidence. Terms that were italic are provided with extra descriptions in the Terminology section to eliminate ambiguity.

2. OVERVIEW

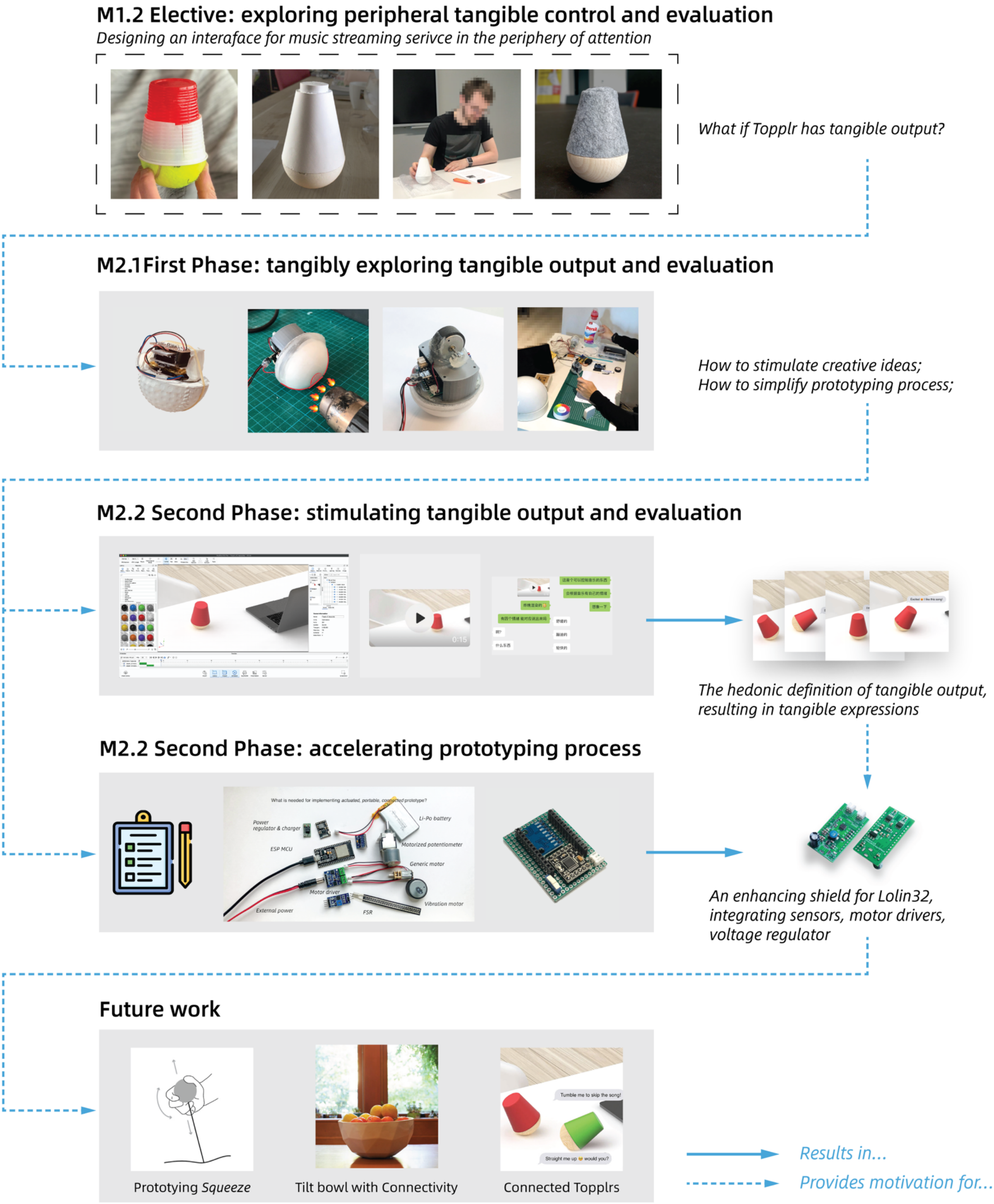

Figure 1 A visual roadmap of the design activities and reflection synthesis

3. FIRST PHASE

The first phase of this project (M2.1 FMP Preparation) focused on defining the project scope: *Design System Output. B*y starting the investigation in peer-viewed designs, exploring and framing the design objectives, which turned out defining the main topic of this project as *designing tangible outputs of everyday objects*. Next to that, more in depth literature reviews regarding the interaction theories were conducted to frame explicit design rationale and concepts.

3.1. Motivation

In this phase, the study was initially motivated by a personal interest as a product designer, aiming to bring tangibility to the everyday interactions. Such an ambition doesn't come up without a reason.

As the maturation of ubiquitous computing, an increasing number of everyday objects are able to proactively offer context-aware services to the user. These smart devices are becoming wireless connected and the communication between each other have become more implicit and invisible. To retain the interaction between human and system, a screen-based or vocal-based interface is commonly and widely applied. As a result, humans tend to spend most of their time interacting with, in Victor's words, a "Picture under Glass" (Bret, 2011).

Due to the following facts about tangible interface, 1) it supports immediate interaction in the periphery of the user's attention, freeing the cognitive resources in performing interactions; 2) it stimulates intuitive reflections and meaningful understanding of unexpected or unfamiliar system manner (Schmitz, 2010); 3) it leverages human's inborn manipulating capabilities (Ishii et al., 2012). Given the mentioned benefits, recent research haven been instigated into creating actuated designs (Dimitriadis and Alexander, 2014; Kinch et al., 2013; Yasu et al., 2014). Yet, much of the design tend to be fixed in at a place and haven't been widely integrated in a living environment, leaving an intangibly interactable smart home.

Such a situation leads to a research project, "Besides pixels and sound, what *tangible output* be like in the future smart home?"

3.2. Background

In 1997, Weiser and Brown addressed the challenge of designing calm technology for the emerging era, ubiquitous computing, from which they stress the need to stay in control of the technology that would surround us and prevent us from information overload by digital devices. Many have built upon this vision, resulting in various explorations of approaches to leverage the capability of technology while also containing its consequential obtrusiveness.

3.2.1. Interaction technology

One early exploration focuses on seamless integration of digital bits in the physical world. In 1997, Hshii and Ulmer introduced Tangible bits (Ishii and Ullmer, 1997), a concept in which they sought alternative means of interactions other than GUIs. They augment objects from the physical world as interfaces with the coupling to the digital world namely Tangible User Interface (TUI), which is to compensate for the lack of natural affordances of GUI ones. However, as TUI is often being constrained by its static physical form, to further disclose the potential of being tangible, Hshii further proposes the concept called Radical Atoms (Ishii et al., 2012), which envisions to give physical representations for every bits from the digital world, allowing humans to seamlessly and directly manipulate the digital world.

3.2.2. Calm technology

Another a bit recent exploration stresses on the level of required mental effort of interactions. Specifically, continuing upon the divided attention theory (Miller, 1982) (a theory addressing attention as the division of mental resources over different activities (Wickens, 2008) and multitasking theory (Salvucci et al., 2009) (which stresses on the mental resources can be allocated on different tasks), Saskia proposes interactions can be categorized and distributed on a continuum (Saskia Bakker and Karin Niemantsverdriet, 2016) from focused, peripheral, and implicit interactions with identical characteristics. She believes by leveraging peripheral interactions to bridge the gap between two extreme sides on the continuum (focused and implicit interactions respectively) is a way to reduce the obtrusiveness of our everyday objects.

3.2.3. Intelligent technology

Besides, due to the emergence of Artificial Intelligence (AI), Voice User Interface (VUI) [16], an intangible interface, in the form of Virtual Assistant, is introduced and has been made popular by Siri (Aron, 2011). It is seen as the embodiment of humans, initially allowing users to fetch information (e.g. weather, time, navigation) and nowadays offers users rich and explicit control over the connected devices. Most of the VUIs mainly rely on speech-sound, to perform certain control, a user has to memorize the vocal commands. Consequently, physical buttons are usually removed from these interfaces.

3.3. Related work

3.3.1. Living with Smart Home

As Internet of Things (IoT) invading modern homes, more and more smart products have been brought to the market and deployed in our homes or home-alike contexts. Most of these devices and services are usually controlled by VUI (Schnelle-Walka and Lyardet, 2006) in the form of Virtual Assistants which allow users to prompt questions and control the system. The three most prominent competitors in this field are Google Home ("Google Home," 2020) Alexa by Amazon ("Echo Dot," 2020), Siri by Apple ("Siri,"). Also most of these smart products (e.g. Philips Hue ("Philips Hue," 2020), Smartmi Air Conditioner ("Smartmi AC," 2020)) are accompanied with Graphical User Interface (GUI), in which users can have explicit control over the parameters of corresponding applications. Taken together, Flyzoo Hotel (*Alibaba Flyzoo*, 2020), a hotel almost entirely run by robots, presents a highly integration of the above-mentioned elements or alike, bringing users a sense of futuristic home.

Yet, interfaces served on these products or services are usually voice- or visual-based and to understand them, intellectual-motor skills are mandatory. As a result, performing interactions through these interfaces would demand users to shift their center of attention onto them (Saskia Bakker and Karin Niemantsverdriet, 2016) or their intellectual-motor skills.

Figure 2 Dangling String

Figure 3 Topplr - tumbling to skip a song

3.3.2. Peripheral interaction

Peripheral Interaction initiates from calm technology, aiming to offer effortless control of the computing system or present information subtly which allows users to perceive in their periphery of attention. An early example developed by an artist, is the Dangling String (Weiser and Brown, 1996) (see Figure 2), a live wire connected to the ceiling that subtly wobbles itself to inform office workers' the network activities. Similarly, Move-it sticky notes (Yasu et al., 2014) (see Figure 4), an mechanism that actuates office sticky notes by adding motions to subtly notify users of their upcoming tasks. More recent examples include *Topplr* (a master's student project from ID, Figure 3), a music controller which allows users to skip a song by tumbling it down. Similarly, Breathe-in, exhibited at the Dutch Design Week 2019, allowing users to skip a song or flip a page on an e-Reader by holding a breath for a certain duration.

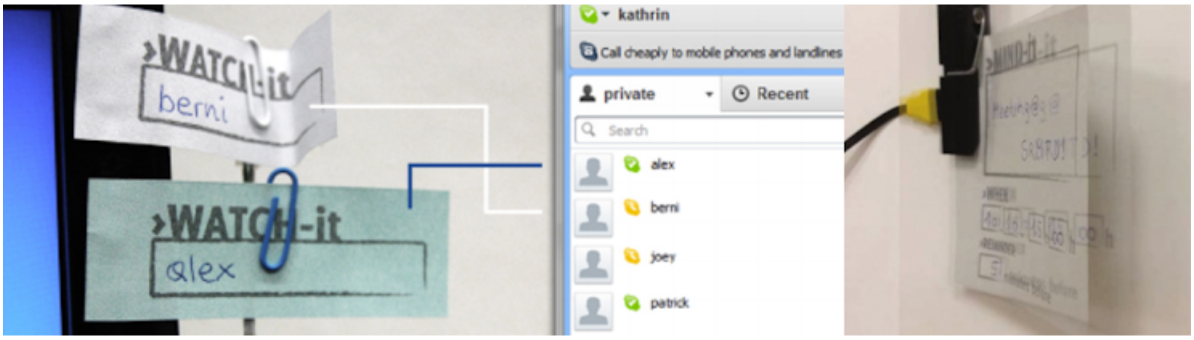

Figure 4 Move-it, an actuatable paper clip, representing the user's status by different shape of

However, it seems these mentioned interfaces by far only emphasize on their inputs or outputs. For instance, there is no way for *Topplr* to output information in one's periphery of attention as Dangling String, and vice versa. Besides, despite the fact that Move-it incorporates both outputs (subtle motions) and inputs (creating a reminder), writing and setting a reminder still demand a person center of attention. There's still space for how to enable the user to input in his/her person's periphery of attention.

3.3.3. Shape-changing/actuated interface

Research on shape-changing/actuated interfaces has been maturing. Many in the TUI field have explored overcoming the constraint of static forms of TUI, which populates shape-changing interfaces. One of which is inFORM (Follmer et al., 2013), which transforms digital pixels into individually addressable pins with a beam on top projecting augmented elements (see Figure 5). This demonstrates researchers the capabilities of shape displays: 1) provide physical affordances; 2) restrict behavior by adding constraints; 3) actuate movements; Researchers have explored to apply them to affect behavior shown as Thrifty Faucet, a shape-changing faucet (Togler et al., 2009) (see Figure 6)which can turn, twist its body to express different emotions. The same as the shape-changing bench (Grönvall et al., 2014) in the public spaces (Figure 8), the bench actuates upwards to encourage people who sit in the distance to move closer to each other.

Those shape interfaces either serve as system outputs to convey pragmatic or hedonic information (Rasmussen et al., 2016), or focusing on how shapes (or force applied onto the shape changes) can act as system inputs as what (Rasmussen et al., 2012) calls, *indirect interaction*, adopting implicit input and shape-changing output (Figure 7).

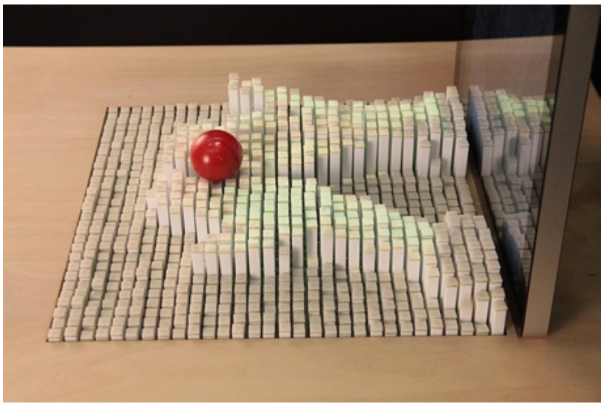

Figure 5 inForm, most representative example of actuated display

Figure 6 Shape-changing faucet

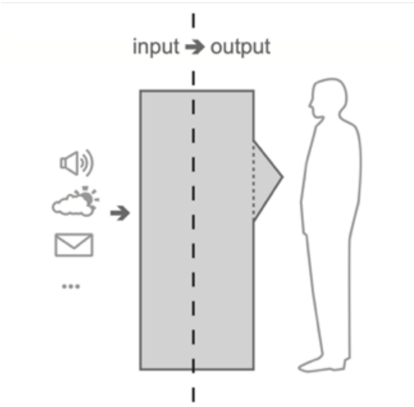

Figure 7 Indirect Interaction

Figure 8 Shape-changing Bench

3.4. Design rationale

Based on the previous investigation, an elaborated design rationale, consisting of five aspects for answering the proposed research question is developed.

For home/indoor usage

The targeted context of application is set to an indoor environment. As actuated interfaces haven't been widely introduced in the everyday home scenario, much of the design space in such a context remains unexplored. What is the role of *tangible output* in the everyday life?

Non-obtrusive

The actuation of the interface shall be as gentle as possible. As different the actuating mechanisms usually involve gears, rotators, which tends to cause significant acoustic issues. During the prototyping, actuator selection should carefully take this consideration into account.

Bi-directional interaction

As the interaction of the actuated interface is envisioned to allow both *tangible control* and *tangible output*. Not only should it allow the user to control the system from a physical input interface but also the interface should be able to actuate in return.

Intuitive interaction

The interface shall preferably leverage human's perceptual-motor skills instead of cognitive-motor skills. What GUI and VUI don't leverage well humans' heightened ability of sensing and manipulating is what tangibility can compensate.

Intriguing interaction

Making things interactable and actuatable isn't just enough. A conventional fan has already met all mentioned design criteria. How to incorporate humor, life-likeliness into the concept would be another challenge.

3.5. From rationale to concepts

During the brainstorming phase, the process was mainly inspired by a question:

"What if an input-only interface from our everyday allows actuation?"

3.5.1. Method

To concretize abstract design rational into concepts, a traditional approach to creativity, *brainstorming* and a systematic ideation method, TRIZ (Altshuller, 2002) were adopted. First, explorations of design precedents and theories were investigated. This step was to look inward for inspiration; Then, seeking opportunities where TRIZ principles can be applied; Lastly, evaluating the generated concepts have met the defined rationale.

3.5.2. Procedure

In synthesis of the design precedents, an interesting finding was some designs focus on physical input while some emphasize on the tangible output. This brings one of the principles of TRIZ, *Consolidation* to play. This is, if an interface is input-only, how would it be if it can actuate?

The exploration was later inspired by and grounded on the physical input taxonomy (Zheng et al., 2019), a framework covering five mechanical mechanism with different physical constraints, namely Linear, Angular, Polar, Planar, Radial. As some cases involve volume-changing or shape-changing, so another subgenre spatial is appended at the last column. Based on that, corresponding tangible output example for each type were explored as shown in Figure 9. For example, tangible output could have been implemented on *Topplr* (e.g. self-tumbling) to subtly suggest users skip context-unmatching songs; Binary control could have been integrated on Move-it (Yasu et al., 2014) to snooze the reminder by gently patting the shaky note using user's perceptual motor skills.

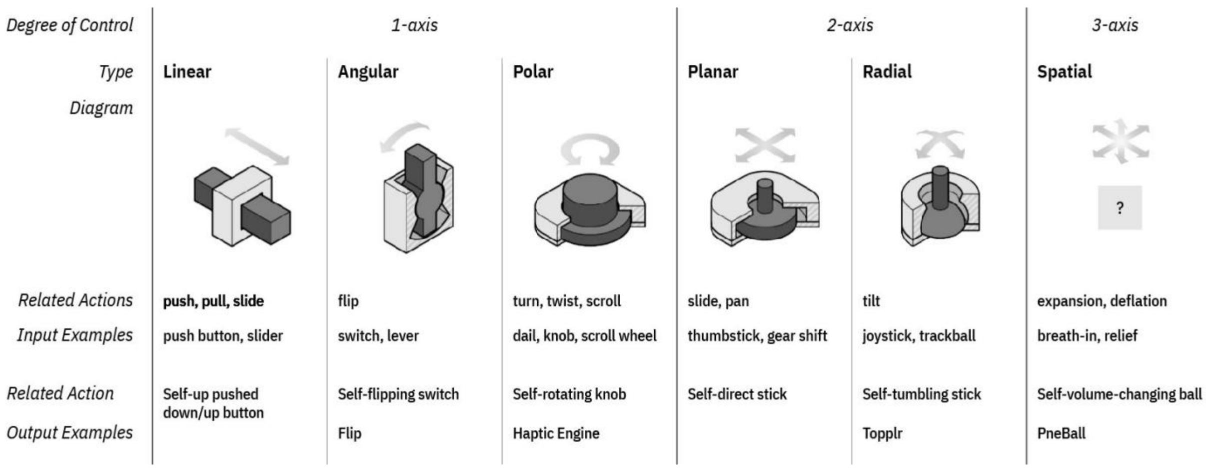

Figure 9 different spatial constraints with supported actions and examples of controllers

3.5.3. Selected concepts[1]

Topplr was selected out the other two concepts. Topplr was initially a roly-poly like[2] prototype made out of foam, offering five *tangible control*, changing volumes by rotation, skipping songs by tumbling, pausing/resuming by squeezing. The fascinating part of Topplr is, that it's able to straighten up itself if it is tilted. As mentioned previously, Topplr could also have had subtle output as well. Thus, this project stresses on the implementation of that. Topplr can tumble itself down to notify users skip a context-unmatching song, as consistent as what it meant to be for the tumbling.

3.6. Concept prototyping

3.6.1. Electronics selection and implementation

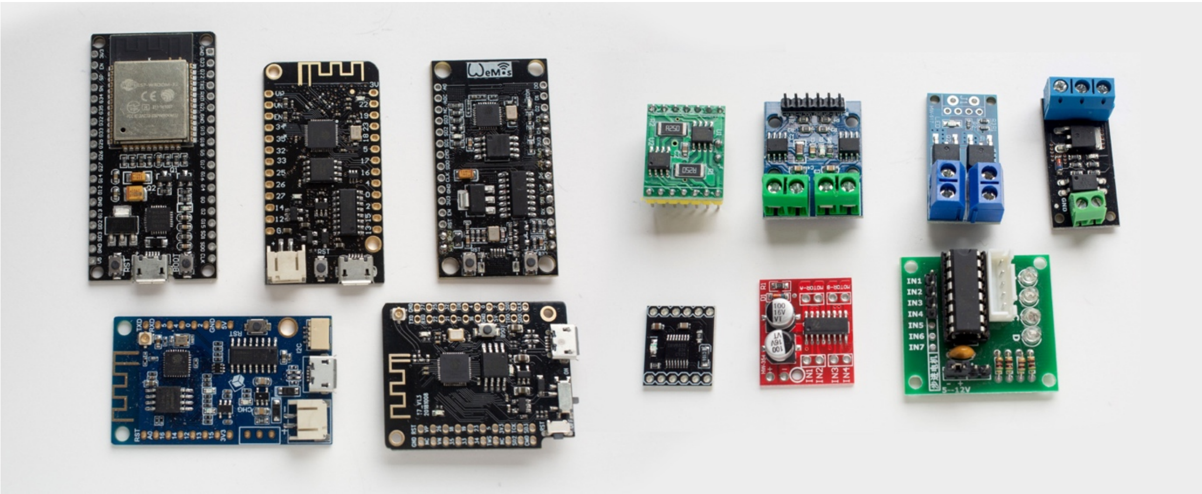

Figure 10 Electronics selection

Before straightforwardly divining into prototyping, electric components were explored (Figure 10) and selected to ensure the feasibility[3] of the prototypes with multiple comparison charts. As during this phase, the desired concept hasn't been confirmed, the selection of the electronics. To shrink the overall circuit dimension, circuits were carefully drawn with a pencil before getting soldered on the double-sided padboard. Then, the modules and complementary components were wired up on the board. The prototype in this phase has quite some overlapping with the one that will be introduced in Chapter 5. The included components and corresponding functionalities will be introduced there.

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[1] Besides *Topplr*, there were two prototypes (*Flip, and Pneball*) generated and developed tangibly but later decided to be doomed as they were not as matching the design rationale as *Topplr* was. Thus, both of them were achieved in Appendix B.l

[2] One kind of toy that is able to straighten up itself if it is tilted.

[3] During the exploration, there were some technical encountered obstacles, which returned in many starting over prototyping activities. It is mainly about the struggling with incompatibilities between desired purpose and the capability of the module. For example, the motor driver module was altered from a PWM Mosfet, to an H-Bridge dual channel module (*DRV8833*), to allow directional control but it was again changed to *L9110s* as the prior one can't tolerate 10V and above. Those issues might have been avoided if technical investigations were made more sufficient.

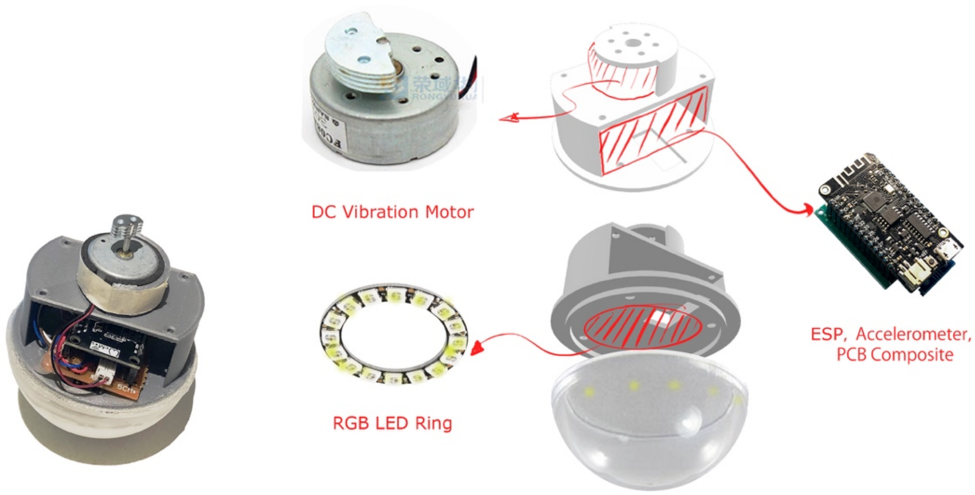


Figure 11 an exploded view Topplr with electronics developed in this project

The original prototype from the prior project was a mock-up for Wizard of Oz. Yet, such a prototype provides low feasibility to conduct a Wizard of Oz as there is no way to make it actuatable. Thus, a functional prototype is developed (see Figure 11), which integrates a mechanism to shift the center of weight of Topplr; a 3D printed mount is made to hock the RF300 Vibration Motor on the top, a circuit composite (integration of *ESP8266* (but later upgraded to *ESP32* as Bluetooth is a necessity), *AXL345* accelerometer (later upgraded to *MPU6050* as Gyroscope is required to measure the horizontal rotation), and a RGB LED Ring attached at the bottom of the rack, being covered with an acrylic semi-sphere.

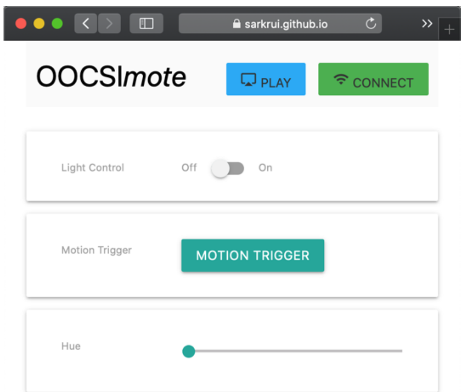


Figure 12 OOCSImote, the wizard platform

As the *tangible input* of *Topplr* has been defined and evaluated in the elective, in the phase the functionality inherited but further implemented. Thanks to the ESP wireless connectivity (Wi-Fi and Bluetooth), Topplr functions as described and can be remotely (e.g. OOCSI-mote) controlled (see Figure 12).

3.6.2. Tangible prototyping explorations

As the electronic side was implemented, the tangible prototyping explorations followed up consecutively. In this section, the goal was to explore different kinds of tangible output possibilities. In a technical sense, it was mainly about the back and forth modifications between software and hardware. As for the software, it was about configuring the parameters for spinning *duration*, *direction*, and *levels of voltages* of the motor; As for the hardware, it was to explore different *orientation* of the motor, *shape* of the bottom of *Topplr*, as well as the *center of weight* of the rotator (see Figure 13).

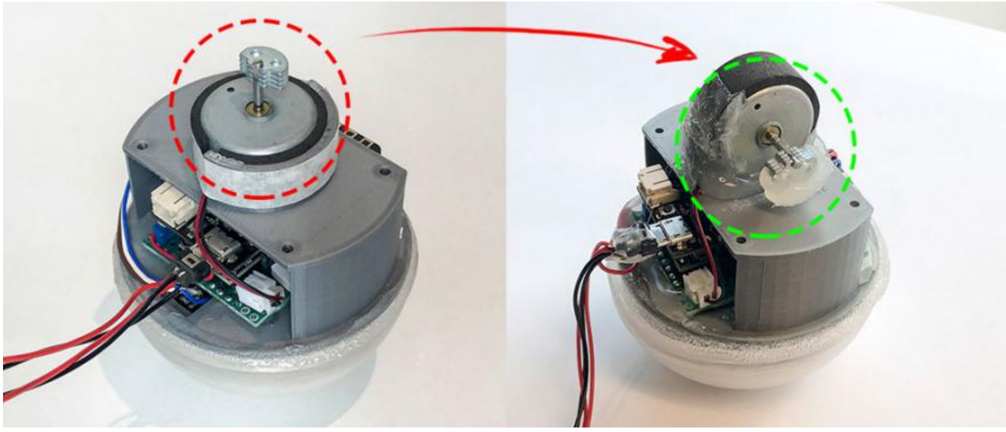


Figure 13 Example of tangible exploration

3.7. Reflections

3.7.1. Prototyping

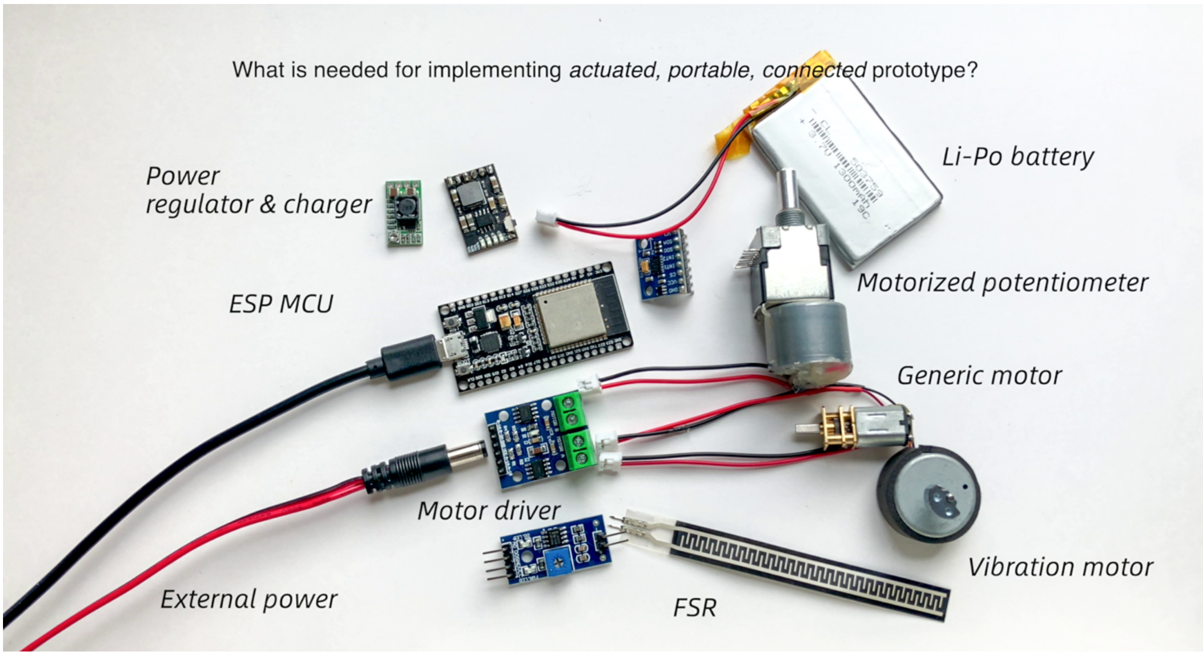


Figure 14 An overview of what might be needed in order to create a portable, actuatable, and tangible prototype with wireless connectivity

In brief, the prototyping challenge mainly lies in the incompatibilities of my prototyping skills and the desired actuation I wanted to achieve. Before this project, I had few experiences working with actuated interface design, however, the prototyping difficulties increase once it has to be physically interacted with or being compact and portable. Designers have to both ensure the feasibility (e.g. functionality, usability, stability) of the prototype and ideas might promptly pop up during the prototyping, but yet the prototyping skills can't follow along. This could result in many start overs, involving re-routing of the circuit, de-soldering and upgrading modules. For example, during exploring the setup and configuration of the motor, an idea popped up, saying "what if we have two motors actuating in different axes with different software config?". To try out the idea, the 3D printed rack has to be redesigned to mount the newly added motor. Moreover, as Topplr is aimed to be as portable as possible, it was a great challenge to integrate and solder all modules in a small hand-size prototype during the initial prototyping phase.

The above mentioned technical obstacles I encountered also instigated me to reflect on how to simplify the process. For example, the setup of the components (placement of the actuators, modules configuration) can be generalized and shared as design blocks to help other peer practitioners develop their prototypes in the relevant field.

3.7.2. User study

Conducting user study for tangible interaction comes with huge opportunity cost, as the prototype has to be working or experienceable. Although we had Wizard of Oz (Dahlbäck et al., 1993), suggesting to have one hidden wizard manipulating the interactive system, rendering the user experience as genuine as possible, it doesn't seem to be feasible in mimicking haptic experience. This has also instigated me think about other quick and timewise ways of exploration and evaluation.

3.7.3. What next?

As for the prototype, the next chapter will be addressed on how to support and accelerate the prototyping process in designing tangible output; As for the user itself, the following study will stress on how would the user the interpret the *tangible output*? how would they react to it? What does it mean to the user?

4. SECOND PHASE

“[...] It looks like Clubbing. [...]” – P2, Group 2

“[...] my main concern and/or experienced problem would regard the vulnerability of (low/mid fidelity) prototypes that need to be physically interacted with. [...] a lot of vulnerable components come in to play to allow for the change in shape/movement. ” – P7, Group 1

The prior project phase has explored and developed the *tangible output* of *Topplr*, *Flip*[4]. In this chapter, a pilot study was conducted to gain feedback and suggestions. Next to that, an exploratory method of stimulating *tangible expression* in software was explored. Simultaneous to that, a demand acquisition study was conducted involving nine participants.

[4] Flip: a bi-directional switch that allows not only to control a light bowl (on/off) but also suggest the user by actuating the lever.

4.1. Pilot study

This pilot study was mainly scheduled to gain feedback and suggestions on the interaction experience. A 2nd year PhD student participate in this study.

4.1.1. Procedure

First, familiarization, the participant was exposed to *Topplr* and *Flip* in the wild. They were allowed to explore the functionality as they wish (see Figure 15). Second, the wizard manipulated the Topplr or Flip to do certain actuations and took attention to the participant's reaction; Third, exposing relevant actuated design to the participant to enhance their understanding of *tangible output*; Then, a semi-structured interview [5]followed to reflect the participant's experience; Lastly, the participant was suggested to sketch what other *tangible output* could be in the everyday life.

Figure 15 Participants experiencing the prototypes

4.1.2. Findings

Based on the interview with the participant, salient notes were abstracted and thematically analyzed into three themes.

Integration of life form

A life form in nature is a type of *tangible output* from the everyday life. The way how life form grows up could be perhaps an intriguing metaphor for introducing the idea of having *tangible output* in the mundane life. Sketches from this pilot study was attached in Appendix I.

Actuation variation supports imagination

"I wouldn't be able to imagine if every object is actuating when I return home.", the participant said. The transition from static to actuating shall be smooth and gentle. Otherwise, it becomes salient and obtrusive to the routine. Thus, supporting different levels of, having the transition from gentle to aggressive would increase the spaces for interpretation.

[5] The interviewed was conducted in the participant's mother tongue, Chinese as it is a casual conversation context and the quotes were later transcribed into English.

Benefit of tangibility

Being tangible might be valuable to the visually disabled minorities as for those people, they tend to be more sensitive to the haptic feedback. Besides, the study did not address on who would be the targeted users, what the benefit is to them

4.1.3. Reflection

The participant noted that there was some struggling when generating other design derivates as the scope was too broad to know where to begin. This could have been better arranged as what (Angelini et al., 2018) has shown using 16 cardboards with predefined fields or functions to guide participants through the study. The introduction or discussion regarding why using actuated interface could been better introduced to the participant, instead of just showing them what they are, if they were unfamiliar with the field.

4.2. Stimulation

4.2.1. Motivation

As described in the prior chapter, evaluating the actuated interface after it's actually built demands too much of effort and time for design practitioners particularly if they had weak electronic and programming skills. Interestingly, according to (Rasmussen et al., 2016), shape changes consist of two types of information, functional and hedonic respectively. Many researches have discussed the relationship between inherent property and affordance, meaning being tangible is key to understanding the functional meaning of shape changes. However, it has not been discussed yet whether being tangible is a necessity to interpret the hedonic meaning. Thus, this section to break through the creativity being limited by the tangible prototyping skills, we explored more *tangible output* in a software environment.

4.2.2. Stimulation configuration[6]

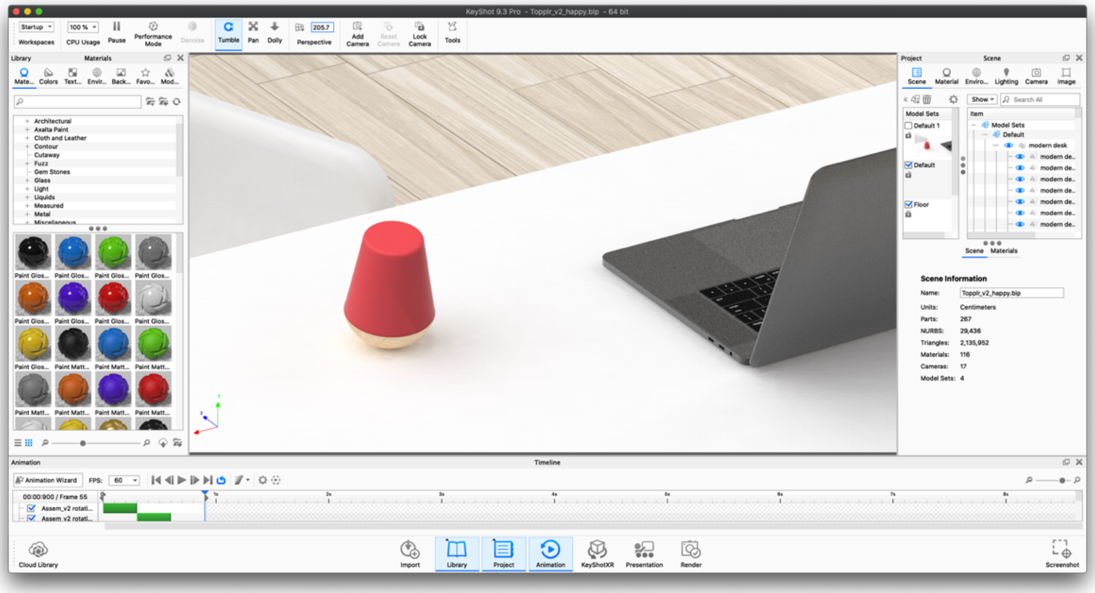


Figure 16 an overview of the stimulation environment, using KeyShot

In general, KeyShot was used as the major rendering tool. All models (the desk, chair, laptop and the wooden ground) were built by SolidWorks to create a realistic indoor environment. Two animation techniques[7] (i.e. Rotation and Turntable) were applied solely or simultaneously. To create a looping animation, the total actuating of each technique should always be a constant zero in one looping unit. For example, in a 1000ms footage (as one looping unit), if Turntable is applied to 30 degree for 300ms. Then, the rest of time (within 700ms) has to compensate for negative 30 degree (see Figure 17). The footage was

[6] Even though it is in a software stimulating environment, the actuation is aimed to be as realistic as possible before on the prior experiences from the tangible prototyping.

[7] This was based on the early exploration we found that using one motor to create horizontal rotation and the other one to create turntable.

rendered at 60 fps (frames per second) with each frame being rendered for 120 seconds max. Thus, rendering a 1000ms looping footage @60fps would take around 2 hours[8].

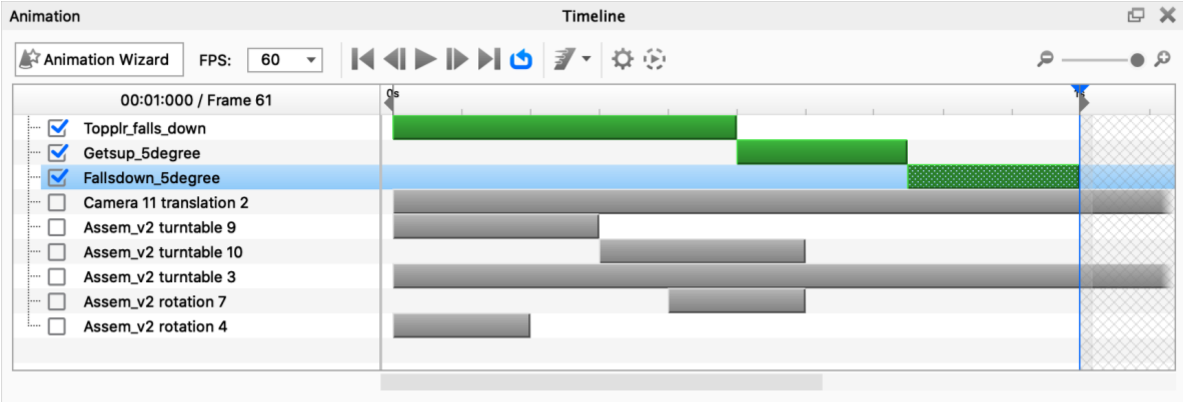


Figure 17 Snapshot of KeyShot animation configuration

4.2.3. Procedure

First, a pilot rendering. To make sure the setting is alright, executing a pilot rendering (render each frame for 5 second max. for example) is a wise option; Second, taking a snapshot of the timeline (or save a copy for the whole KeyShot project for archive); Third, adding the rendering to the queue; Fourth, importing the rendered footages to the editing platform. At this stage, playback speed control (e.g. 2x, 0.5x, or speed ramping[9]), color editing could be applied if needed; Lastly, share the rendered footage (without annotations) to the participants.

4.2.4. Preliminary evaluation[10]

In the prior section, four distinctly different *tangible output* were explored and rendered. In this study, six participants from the circle of friends[11] were recruited. The footage (without annotation) was sent via Instant Messaging (see Figure 18). All participants were both introduced the background of the study and what *tangible input* Topplr has. Then, they were sked to interpret what each *tangible output* meant for a subjective perspective. Overall the majority of the feedback was that the animation was considered as intriguing and dynamic; Interestingly, P2 noted that the most actively actuated output looked like “do clubbing”. Some had also questioned about the value of having such “moving things” at home; Besides, from the Virtual Demo Day there were three participants left their compliment of the animation with one wondering if the actual prototype was built in the end.

[8] This may sound a lot, but it is still much faster than building an actual tangibly experienceable.

[9] Speed ramping or time remapping is to have slowing down and speeding up of one footage.

[10] The study was not conducted under strict user evaluation setup. It took place in a daily conversation and then the video was dropped in the dialogue box.

[11] Those participants were labeled as Group 2.

Figure 18 Snapshot of the online interview

4.3. Demand acquisition

"[...]the Arduino modules should be configured properly. I have had to try out different schematics until I found a working one." – P5, Group 1

Simultaneous to the stimulation, a demand acquisition study was carried out. This study was mainly motivated by the troublesome prototyping experiences in person as well as prior experiences as a prototyping advisor among the peer students.

4.3.1. Prototyping competency questionnaire

This is questionnaire to recruit desired participants but also to learn their competency in tangible interaction, regarding their tangible prototyping skills and understandings of tangible interaction.

4.3.2. Setup

In the questionnaire, identifiable [12] participants go through the below steps, 1) categorizing peer-reviewed design cases; 2) describing their prototyping skills; 3) prototyping a portable and actuatable interface that can be controlled over Internet. In the final, participants were allowed to freely leave their previous prototyping experiences. A complete questionnaire can be found in Appendix F. The participants were selectively recruited, resulting in 8 practitioners with design background (ranging from low to high prototyping competency) and one with linguistic [13] background (P9).

4.3.3. Findings

Insufficient knowledge

[12] Making participants identifiable will allow to further user study to be conducted with them. The whole procedure was organized under GDPR.

[13] This participant was set as a baseline, to evaluate how objective the questionnaire. To avoid polluting the data, this participant was excluded from the analysis.

In terms of the terminology, all participants reported that they were not sure about the differences between *tangible interaction* and *physical interaction* even though two of them managed to categorize the design cases 7/7 as P7 said, "*I am not sure anymore, I thought tangible interaction is something to do with changing / shaping a product. Something you feel or touch and can change it. Physical interaction is more static?*". In regards of the electronics, 2/8 knows the how to drive a generic DC motor in an ESP system (with certain driver modules); 1/8 knows how to regulate power although she has to investigate what specific module is required; All participated students have neither skills nor knowledge in designing a PCB board on their own; Troublesome events also took place at D. Search (a rapid prototyping lab at Atlas). I was referred by the technician to a bachelor's student regarding how to drive a DC motor on an ESP.

Lack of tools

When there is no such a tool, you have to build it on your own. "*There is no plug and play solution for vibrotactile prototyping for ESP32. I have to roll back to use an Arduino UNO paired with a motor shield and that is why it is wired and cumbersome*." (reviews from a master's student who is designing vibrotactile experiences). The lack of exclusive board for actuated prototype (that allows remote control) results in extra effort to manage the power supply. "*As the vibration motor draws 9V while the UNO draws +5V, I have to power them individually with two cables.*" (the participant continues).

Fragility of prototypes

Fragility is one of the most confronting parts. Unlike prototyping in CAD or other digital prototyping platform, prototyping tangible concepts involves the consideration of mechanical constraints and flexibility of interaction. If the mechanical constraints or supports are not configurated properly, the prototype is prone to break out. As P8 reported that particularly for the prototype of tangible interaction, where the prototype involves tangibly interacting with, the fragility was one of his biggest concern.

A complete table of analysis (including scores, sortation) can be found in Appendix F-2

5. FINAL DESIGN

The previous activities have contributed to the final designs, *Topplr* and *ESPBoost*. Firstly, *Topplr* is an emotive interface for music streaming services, not only allowing the user to tangibly control the music but also allowing the interface itself to express its emotions with different wobbling techniques; As for *ESPBoost*, it is an ESP32 Shield to accelerate and simplify the prototyping process particularly when Internet connectivity and tangible interaction are involved simultaneously.

5.1. Topplr: an emotive tangible interface

"A commonly used approach to portray emotions is to use organic and life-like movements." - Baum, 2015

5.1.1. Tangible control

As for the *Tangible Control*, Topplr allows the user to skip a song by tumbling; change the volume by rotating; play and pause music by squeezing (see Figure 19). The aim for the design of Topplr was to design interactions that would require a minimal amount of mental resources, so they could be performed in the periphery of attention. Thus, keeping most mental resources available for the working task at hand to be performed in the center of attention.

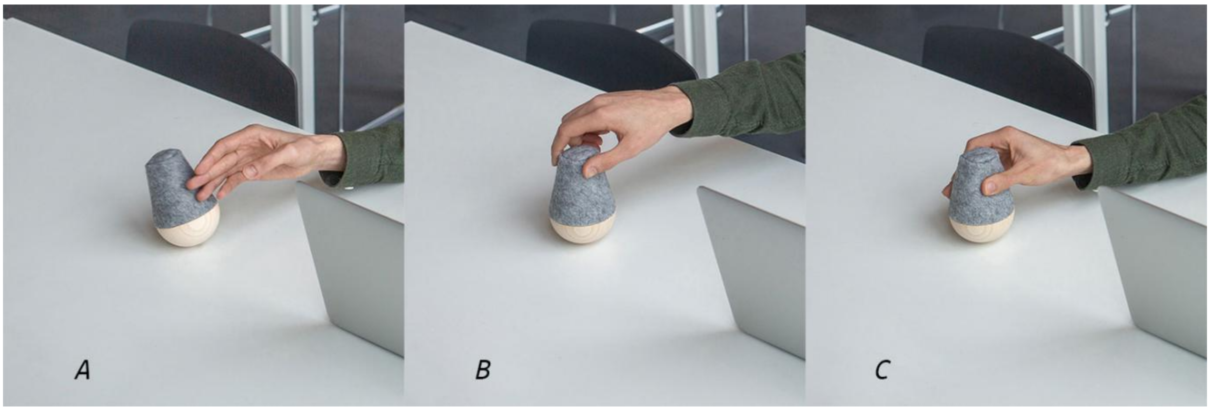


Figure 19 The tangible control of Topplr, A tumbling to skip a song; B rotating to volume up/down; C squeezing to pause/pause songs

5.1.2. Tangible expressions

Figure 20 A contextual rendering of Topplr

Topplr isn't just a physical interface to control the music service. It is context-aware and able to develop its own emotion depending on the scenario. It has four *Tangible Expression*, Calm; Excited; Unpleasant; and Exhausted respectively, which are represented in different wobbling techniques.

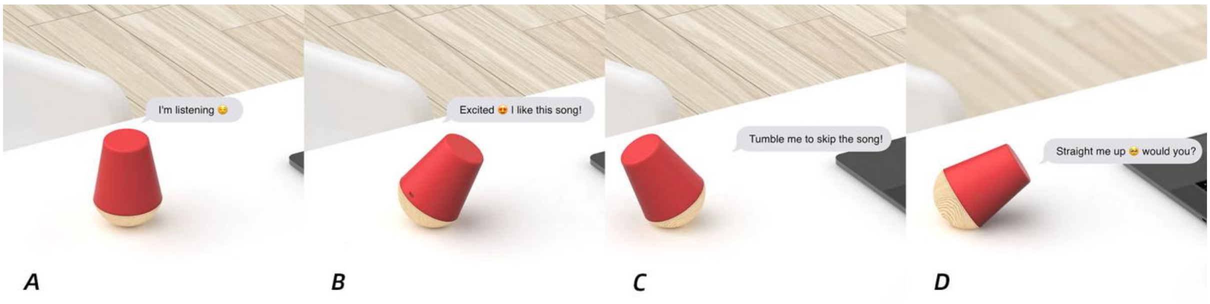


Figure 21 Four tangible expressions of Topplr, *A: Calm, listening to the music; B: Excited, Really enjoying to the song; C: Unpleasant, asking for tumbling; D: Exhausted, asking for help.*

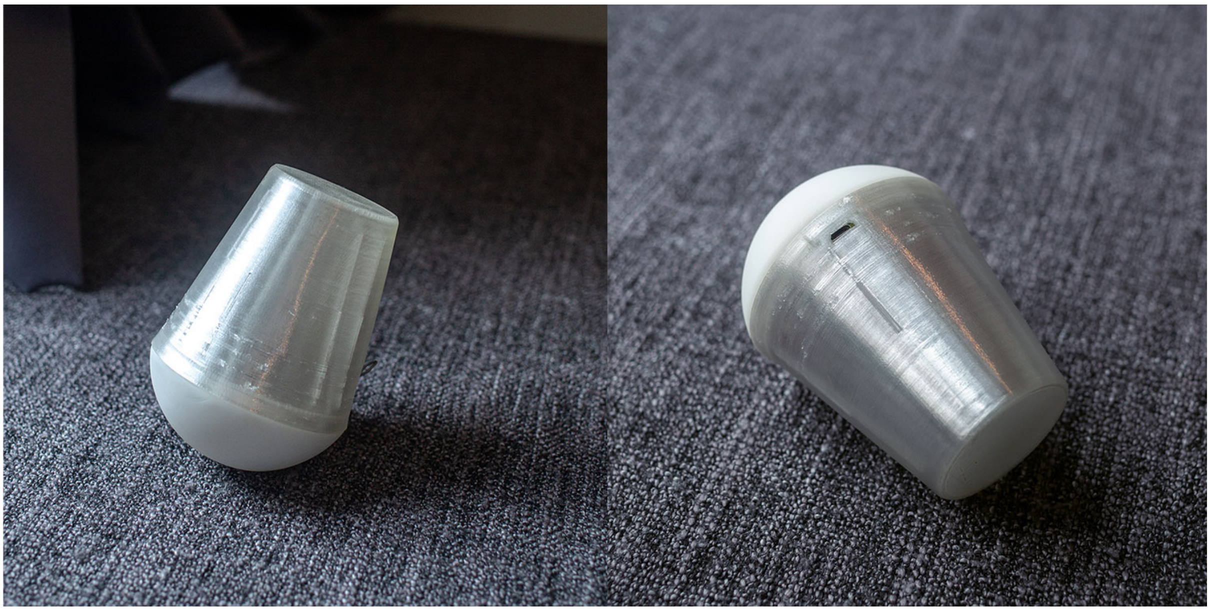
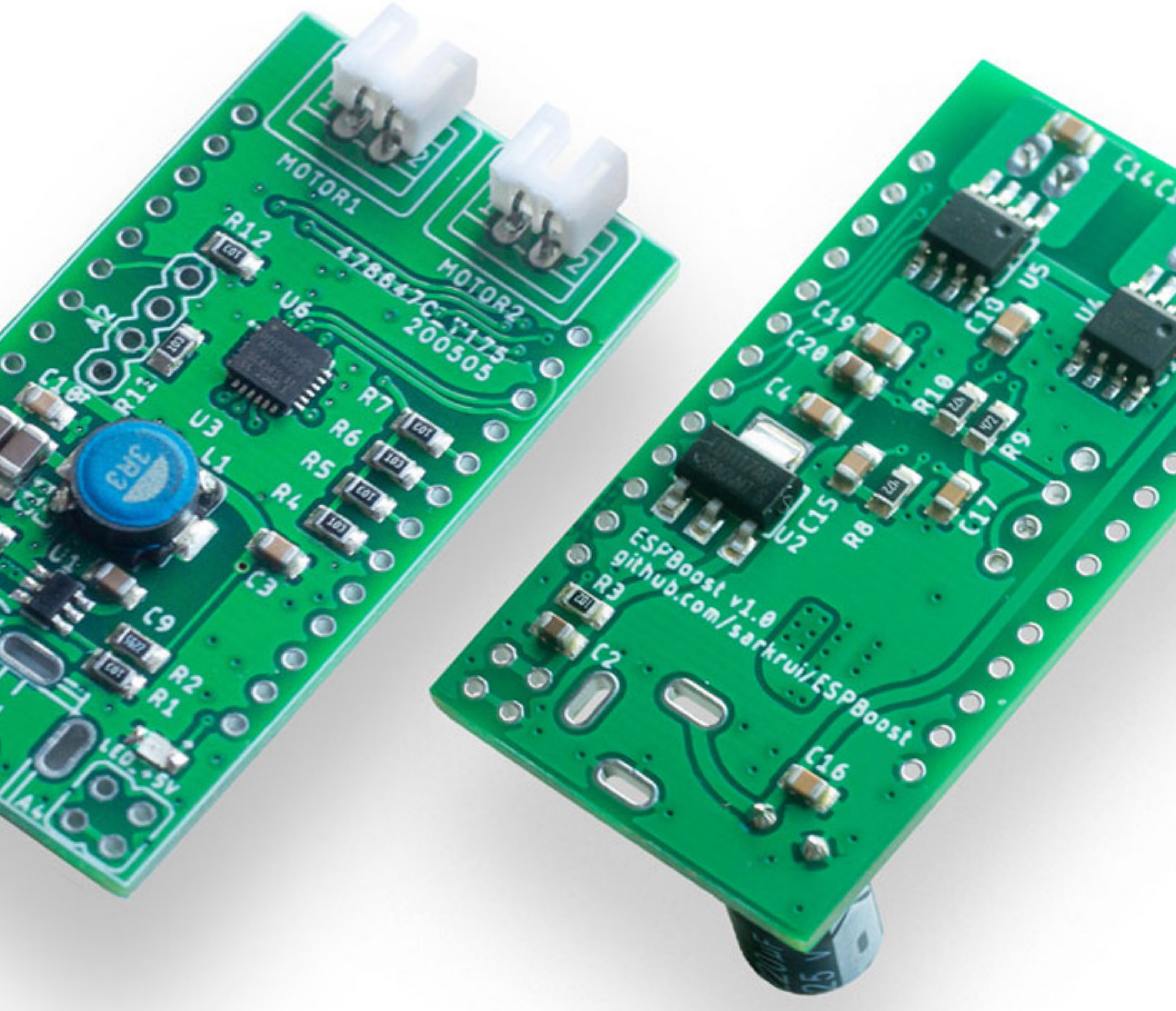


Figure 22 Topplr in plain, (right) shows a microUSB charging port

5.2. ESPBoost: an enhancing add-on

“Prototyping shape-changing interfaces requires knowledge of complex electronics and mechanical engineering that go beyond that typically required in other areas of interactive computing—software programming or simple electronics.” - (Alexander et al., 2018)



5.2.1. Motivation

The main motivation was to support practitioners who are interested in developing actuated interfaces that require Internet connectivity, motion detection, force sensing. The technical advancement also lies in the tolerance for technical mistakes commonly made by prototyping novices.

5.2.2. Components overview

Power regulator

ESPBoost integrates a synchronous step-down voltage converter (TPS563201), allowing any voltage within 4.5V to 17V[14] to be converted to 5V for powering up the ESP standalone system. The input power could be any DC power, either a disposable battery or an external power supply. This would allow the removal of the extra USB cable and the whole prototype being portable. As it is synchronous converting (the converted voltage is fixed at 5V), mistakes such as powering up ESP system at a wrong voltage could have been avoided.

Motion Detection

ESPBoost encapsulates a 3-aixs gyroscope and a 3-aixs accelerometer sensor (MPU6050). This would allow the bodily movement such as rotation, tilt angle of the prototype to be detected easily. Unlike soldering the module onto a padboard or breadboard, pre-integrating it onboard would avoid extra recalibrations and provide a more user-friendly installation.

Dual L9110s motor driver

Dual L9110s are integrated to drive two sets of DC motor running at 12V@800mA max. It's current directional and PMW controllable. It is selected to be compatible with the voltage regulator and fits the specs for the majority of the DC motor on the market.

Dual Force Sensitive Resistor (FSR) Connector

ESPBoost reserves two ADC1 ports (GPIO 32, 33) for FSR and they are both pull down with a 10K resistor to the ground, leaving four pin header connectors for plug and play usage. This also avoids the mistake of using ADC2 ports as these ports are not functional when the ESP32 is processing Wi-Fi tasks[15].

---

[14] Opting a synchronous voltage converter could avoid the burn out of the system because of overcurrent or overvoltage.

[15] This was a commonly discussed topic on GitHub community and few peer masters have also encountered it.

5.2.3. How to use

ESPBoost is as easy as to use other shield kits. It is basically a hub attached on a Wemos Lolin32 lite and the designer can plug-and-play the peripherals. The connector standards are JST-2.0, 2.54mm connector headers, and a 5.5mm DC dock (see Figure 23).

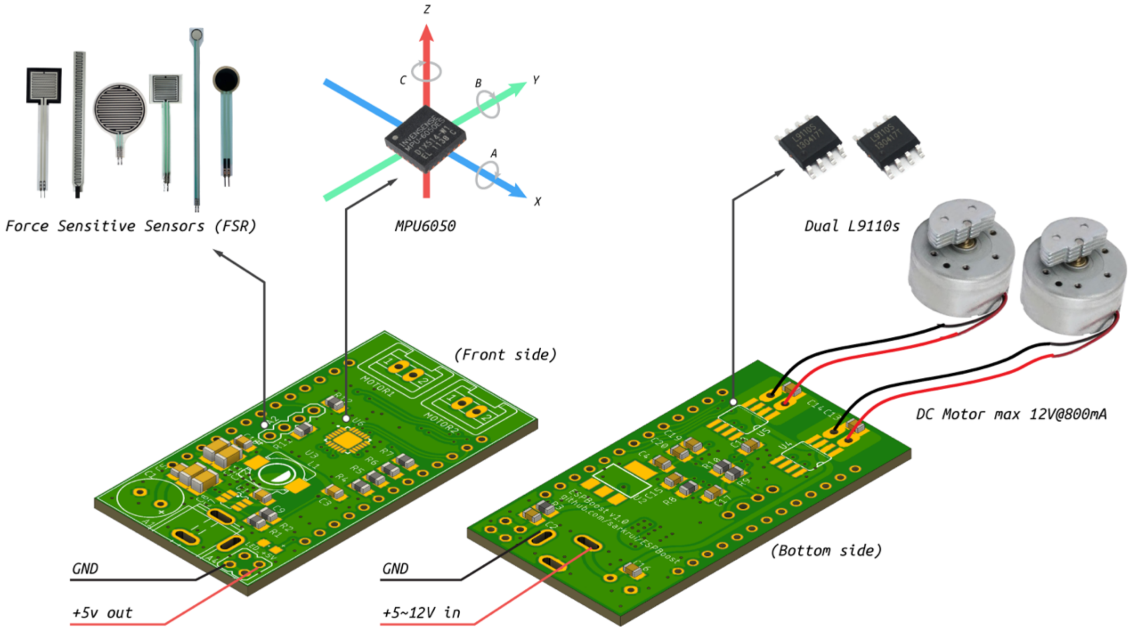


Figure 23 A diagram of connecting peripherals on ESPBoost

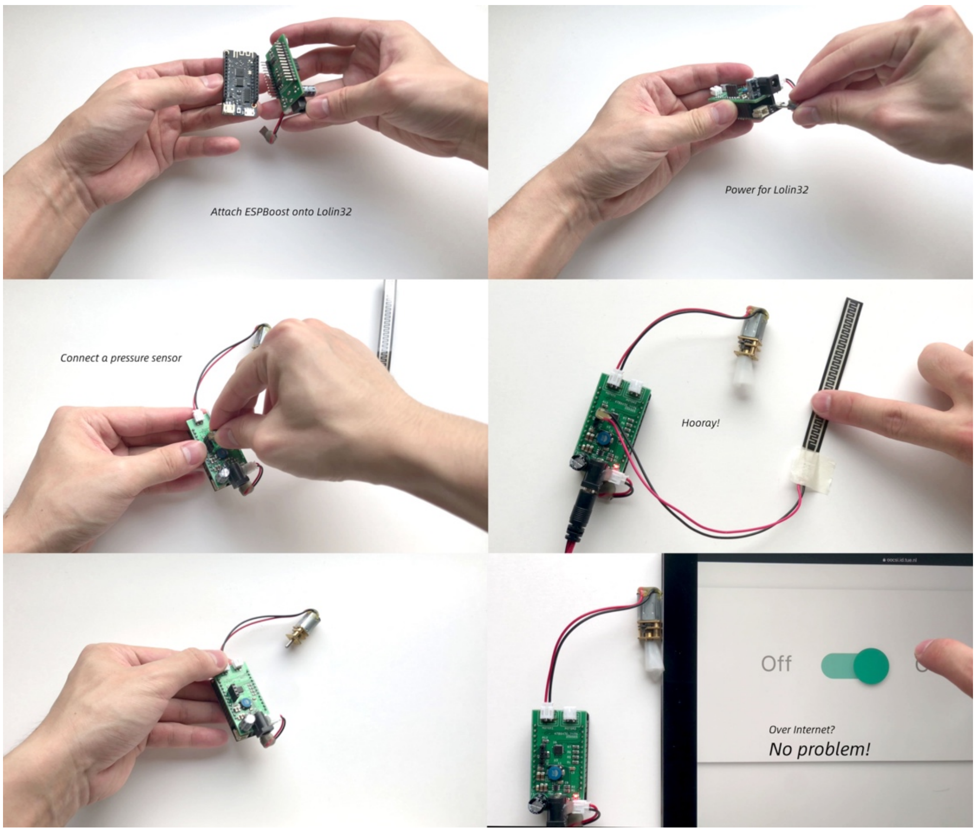


Figure 24 A simple demo of how to control a motor over OOCSI using ESPBoost

5.3. Fabrication

5.3.1. From low fidelity to high fidelity

The infant concept was firstly built on a tennis ball, after a few tangible modifications on the prototype, ultimately evolving to SLA 3D printing models (see Figure 25).

Figure 25 Development roadmap of Topplr

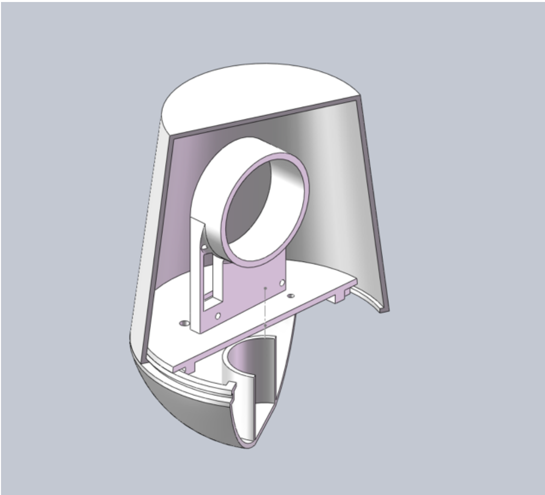


Figure 26 A split view of Topplr CAD model

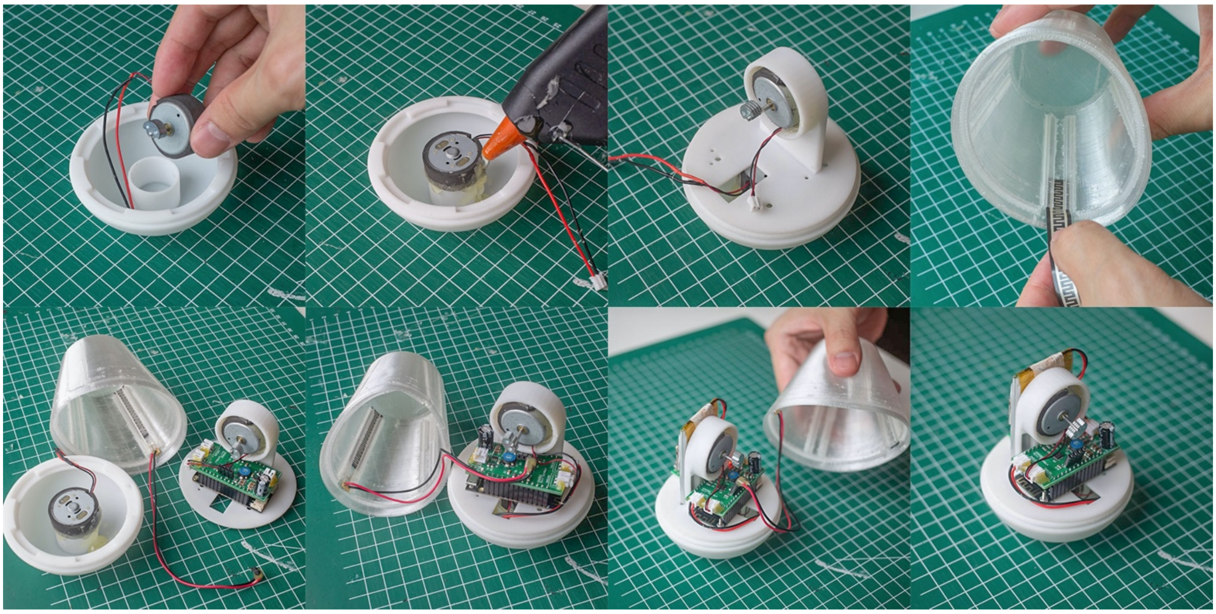


Figure 27 A visual process of the assembly of Topplr paired with ESPBoost

Figure 28 Remotely control the vibration motor on the Topplr

5.3.2. From padboard to customized PCB

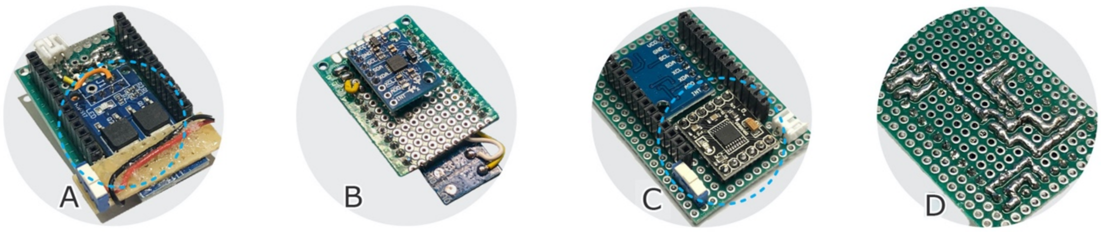


Figure 29 The explorative process of design the initial ESPBoost

Selected modules and complementary components were first experimented on a padboard (see Figure 29) to validate the compatibility. The infant schematics was drawn by me as discussion material with two experienced technicians from China. One of whom was responsible for the modification of the factory ready PCB routing design and the other was in charge of the board producing and soldering.

6. DISCUSSIONS

6.1. Business value

Up till now, having invested sufficient effort of investigation of the existing add-on for the ESP ecology, no similar shield was discovered and that is where ESPBoost can contribute. Since *ESPBoost* is an opensource project (including schematics, PCB Gerber drawing, components list) and has the adaptability for other ESP32 derivates. Any experienced electronical engineer could easily re-define the pinout to adapt to the desired ESP32 board(s).

6.2. Design application

IoT Tilt Bowl

ESPBoost and Lolin32 could be applied onto Tilt Bowl (Lin et al., 2019) to gain Internet connectivity. For example, it would allow Tilt bowl to proactively add a notice on the grocery list; The fruit eating statistics could also be shared over Internet, creating an '*Online Healthy Community*'

Implementing *Squeeze*

Squeeze is a peripheral interaction example from (Saskia Bakker and Karin Niemantsverdriet, 2016). It initially supports four types of interactions (see Figure 30). With *ESPBoost*, not only did the interactions can be made possible, more things such as haptic feedback, acceleration could have been incorporated.

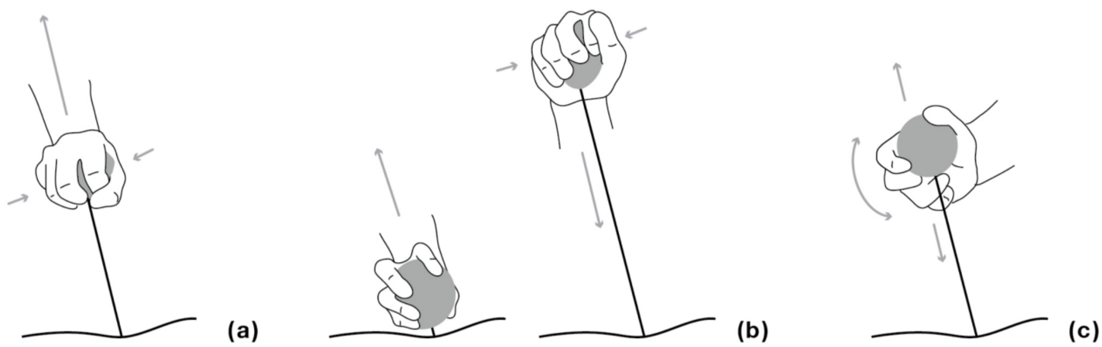


Figure 30 Interaction with Squeeze

6.3. Research direction

Leveraging symmetry peripheralness

Topplr also instigates the reflection on how to better peripheral interaction. *Topplr* was aimed to consider both tangible input and output of the interface, offering effortless control and gentle expressions of emotion. With such considerations in mind, *Topplr* might allow users to perform *tangible input and* perceive *tangible output* in their periphery of attention, namely symmetry *peripheralness.* However, it seems many interfaces where peripheral interactions take place by far only address peripheralness either on input or output but not both. For example, Move-it (Yasu et al., 2014) could have incorporated *tangible input* as opposed to actuate the paper clipper subtly. The *tangible input* could be used for example to snooze the upcoming event for a bit.

6.4. Future design implementation

Internet of Tangible Things (IoTT)

Despite the fact that either *Topplr* or *Flip* can be controlled over Internet, in this project they are still not connected with other things. The interaction among connected tangible things remain underexplored, an area as what (Wakkary et al., 2017) has described, a new type of thing in home that is neither human-centered technology nor non-digital artifacts. What if the *Tangible Expressions* are not just aimed for the human user? What if the *Topplr* itself has a family? How would they tangibly communicate to each other in a shared space? What if the personal music library shapes the characteristics of *Topplr*, representing the embodiment of their user?

Multi-modality interaction

The idea of having multi-modality interaction In this project, the exploration was very much constrained within the field of tangible interaction. However, as music is carried through human's auditory modality (hearing), it might be interesting to explore how would an object show its emotions over sound, or music clips? In that case, how could that couple with *tangible output?*

7. CONCLUSIONS

In this chapter the insights from the design activities are summarized, together with a reflection on the project.

By investigating the design precedents, the project was guided to design tangible output for physical objects in everyday life and the design opportunities were explored. After which together with literature review, a design rationale was constructed to support concepts selection. Ideating based on the mechanical taxonomy, three genres of tangible output with different spatial constraints were defined. Over a course of tangible prototyping, the concepts were made tangibly experienceable for the pilot tests. Concluding from the prototyping process and findings from the tests, two major steps for the next-step development were reflected: a better way to explore and/or prototype tangible output. In the software stimulation and evaluation on the IM platform, participants did manage to interpret the hedonic meaning of the tangible output. This consequently led to the definition of tangible expressions, *calm, excited, unpleasant, and exhausted*; In the prototype quiz among peer-students from Industrial Design department, a majority of the participants reflected the difficulties or lacked relevant knowledge in implementing actuatable interfaces with Internet connectivity. This affirms the necessity of developing a toolkit for these group of people.

With the collaboration of another two experienced electrical engineers, *ESPBoost, an enhancing shield,* was designed and manufactured, integrating common modules (6-axis motion sensor, FSR, motor drivers, power regulator) for implementing tangible interactions. The usage and an example of application were demonstrated though the prototyping process of *Topplr*. The proposed toolkit is a significant step in Internet of Tangible Things, allowing practitioners to bring actuatable interface to IoT with low barriers. Moreover, other applications of such a shield were explored, resulting the discussions of turning *Tilt Bowl* with Internet connectivity, multiple *Topplr*s ecology. Future work is required to evaluate the benefits and/or shortcomings in actual design projects regarding explorations in a stimulated environment, the application of *ESPBoost*.

Acknowledgements

I would like to thank my graduation mentor Ya-liang Chuang for his coaching over the FMP project as well as the previous semesters. While I might have stuck in defining and scoping the project, the weekly meeting and dialogs have certainly helped me clear the puzzles. I also want to thank my examiners (Kristina Andersen, and Jean-Bernard Martens) for giving feedback and constructive suggestion on my project during the Demo Days. I want to thank the technicians from d.search, particularly Geert, Jasper, Chet for helping me complete the rapid prototyping. Lastly, I would like to sincerely thank to my peer students, visitors on the Demo Day, for their feedback and advices.

TERMINOLOGY

Topplr

Topplr derives from the homophonic pronunciation of "tumble", as one of the most iconic tangible control of *Topplr* is to *tumble down* Topplr gently to skip a song.

Physical interaction

According to the TUI model (Ishii and Ullmer, 1997), in physical interaction, the user controls digital information (what happens on a screen) with a physical input device (e.g. a mouse). The overall interaction does not involve direct manipulation of physical representations of the digital information.

Tangible interaction

In contrast with Physical interaction, in tangible interaction, the digital information is computationally represented with dynamic physical forms, allowing the user to tangibly interact with.

Tangible control/input (pragmatic term)

There should have no difference between tangible control/input with physical control/input.

Tangible output (pragmatic term)

A paraphrase of physical representation, to explicitly refer to any tangible form of system output that could be computed by digital information. It is to refer what the system output is.

Tangible expression (hedonic term)

Slightly different from tangible output, tangible expression is given with find certain feelings, opinions, ideas tangible output. It is refer to how the system output feels like.

Shield

A shield is an integrated PCB (printed circuit board) as an add-on to enhance certain board, easily adding features without extra soldering skills or schematics design.

ESPBoost

ESPBoost is an open-source shield explicitly designed for Wemos Lolin32 Lite, integrating the a 3-axis Gyroscope, a 3-axis Accelerometer, a 4.7 ~ 12V to 5V Voltage Regulator, dual L9100s Motor Driver, dual Force Sensitive Resistor Connector.

IoTT

Abbreviation for Internet of Tangible Things, coined by (Angelini et al., 2018). It shall be differentiated from Internet of Trusted Things. In this project, IoTT refers to the overlapping field of tangible interaction and IoT (Internet of Things), a field where every

Peripheralness

A qualitative term to describe the amount of how easy the (peripheral) interaction could be performed, either perceiving the information (system output) or performing actions over the interface (user control).

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APPENDIX

Appendix A: Personal Reflection (FMP Integration)

The three concepts as ideated in the M21 FMP Preparation proved to be infeasible to be implemented at the beginning of the FMP. This was mainly due to the prototyping process might involve many issues that had never been thought about in advance. This could have been avoided if I set up a more elaborative and feasible plan beforehand.

As rapid prototyping is valued as a core of my designer identity, I aimed to further improve my rapid prototyping techniques. After several iterations, I used multiple rapid prototyping techniques with different materials to develop my concepts in different fidelity. I have developed my 3D modelling skills, allowing me to explore my designs through 3D modelling. I became more familiar with the 3D printing techniques (ranging from FDM to SLA), knowing which kinds of materials suit my prototype better. This would allow me working with tangible interactions further in the future; Beside, my rendering skills have developed significantly over the course of the semester. I practiced how to add interior lighting and texture on materials to render a more realistic environment. I experienced how to animate objects in KeyShot for tangible output explorations. This would significantly save the prototyping effort at the early stage of prototyping, compensating the bottleneck of tangible prototyping skills, bringing the gap between sketching on paper and programming with electronics. My personal experiences proved this was valuable during the explorations of TUIs. However, I should have taken more notes and snapshots for each explorative steps for as this might be valuable for report documentation.

The more fidelity design process has allowed me to advance my electronics and programming skills. I, for the first time, became acquainted to Eagle which I am now able to design schematics on my own and later discuss with experienced engineers to customize a PCB board for me. Having such a technique, the future prototypes could be made more compact and easy to be copied and pasted. This can be beneficial for the IoT era where we are surrounded by multiple connected devices. This has also practiced my skills in working collaboratively with engineers, cultivating a mindset of engineering thinking. However, there were some small but cumbersome issues with the module selection (e.g. L9110s isn't qualified working long term under 12V even though this is described as acceptable in the datasheet). In the future, I should conduct more extensive investigation and trial setups of the modules in a long run, before putting them on the PCB in a rush. Meanwhile, I have also practiced writing my own Arduino Library for more efficient programming by packaging commonly used functions into a class. This laid the function of learning object-oriented programming in the future.

Furthermore, I became more familiar with the ethical requirements of conducting human involved experiments in Europe. In order to meet the ethical requirement, the goal, study procedure, and consent form have been carefully thought out. This has allowed to lower the occurrence of mistakes in the following user studies and providing participants a clear study structure. Besides, I have a better understanding of complying GDPR (General Data Protection Regulation) along the study. This would help me avoid the leaking of user privacy in the future studies.

Appendix B: Tangible Output Explorations

Flip

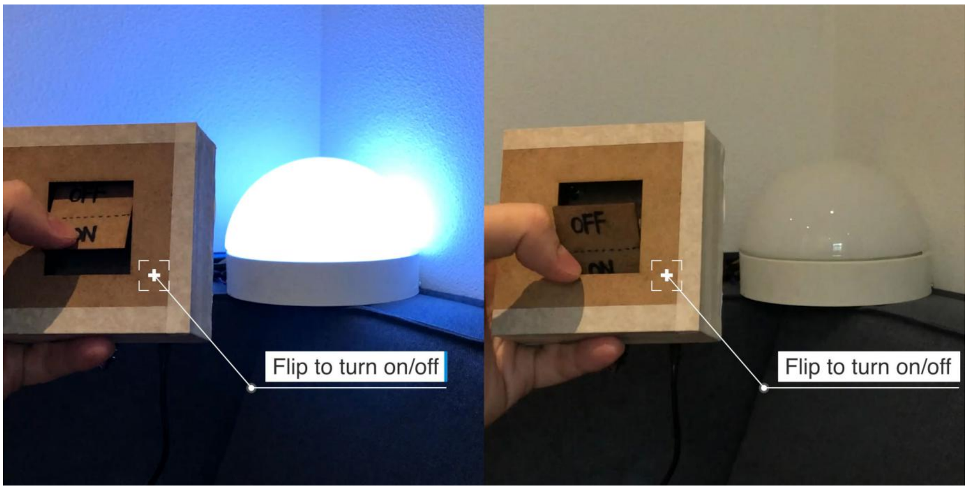


Figure 31 Interaction with Flip

Flip consists of an actuating mechanism (powered by a DC motor) and a sensor (a potentiometer which reads absolute position of the rotator) on the lever. Such an interface operates as other binary (on/off) switch but it can also actuate by self-flipping. This may add some intelligibility to the switch. For instance, in this concept, assuming that Flip is context-aware, it knows when it is suitable to turn on the light and when it is not. The lever can flip outwards or inwards to suggest turning on or off the LED (see

Figure 31).

During the process, as being limited by knowledge, the integration on both sensing and actuation motors was not found. So, I have had to develop a quick and dirty solution by hocking a DC motor on one side of the lever and a potentiometer on the other side. The motor is driven by an Arduino UNO Motor Shield and programmed by an Arduino UNO microcontroller board. The DC motor wobbles back and forth to actuate the lever when it detects a trigger (activated by the author). If the potentiometer reads an ON state, it turns on the LED and stops the motor; Otherwise, the LED keeps in OFF and motor stops.

Figure 32 SLA 3D printed Flip in on state

Figure 33 SLA 3D printed Flip in off state

PneBall

PneBall is a volume-changing interface, aims to explore spatially related control, resembling Canvas (Niemantsverdriet et al., 2018), an interface that allows users to draw the area to which they expect the light setting (e.g. temperature, luminosity) applies (combined together with Breath-in(P, 2020) , an elastic band that measures the volume changes of chest (as input) and inspired by the pneumatic container from(as outputs), a haptic and shape-changing interface is ideated. It consists of three states (see Figure 34):

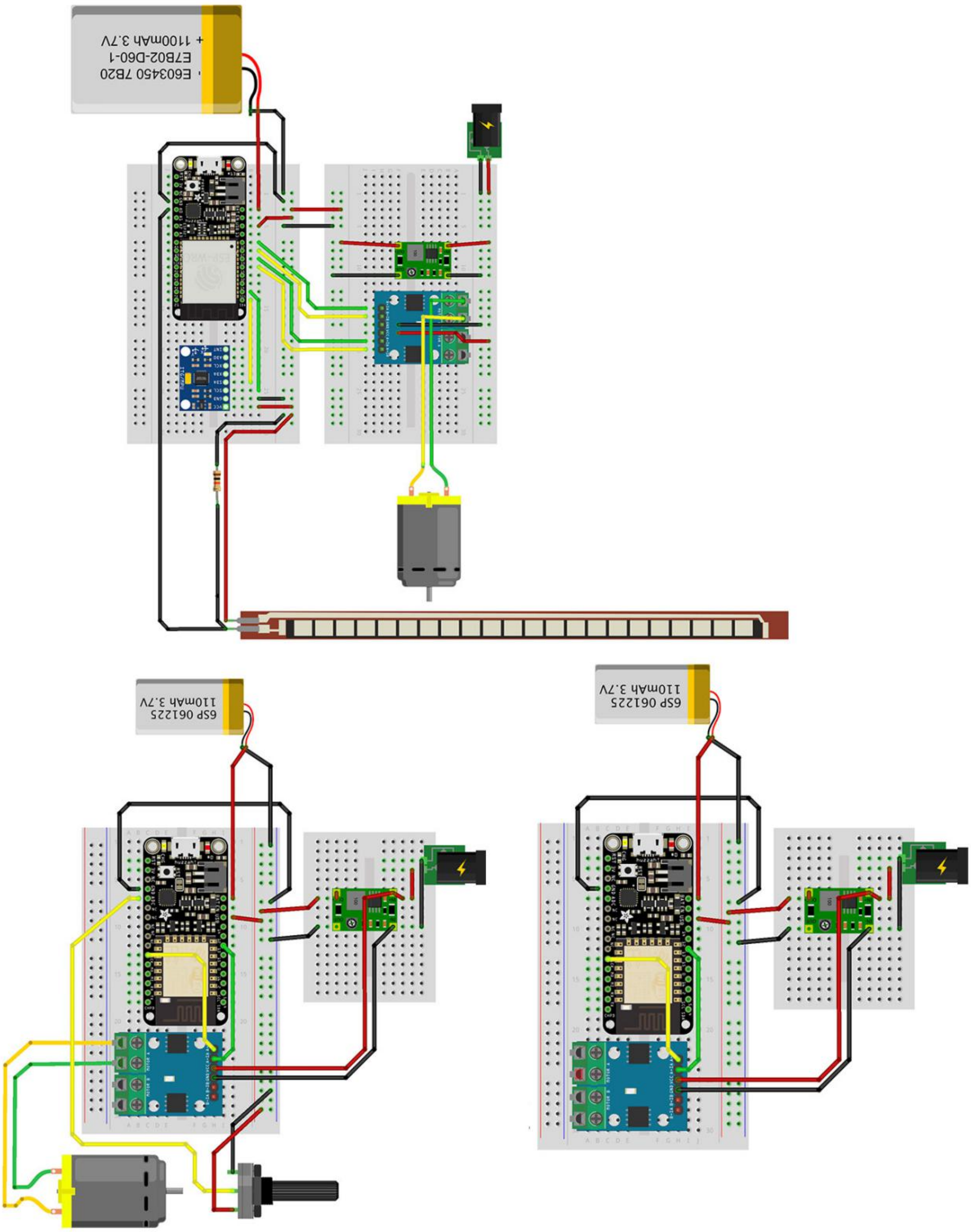
1) when a user takes a deep breath, PneBall inflates;

2) when holding a breath, PneBall keeps its shape;

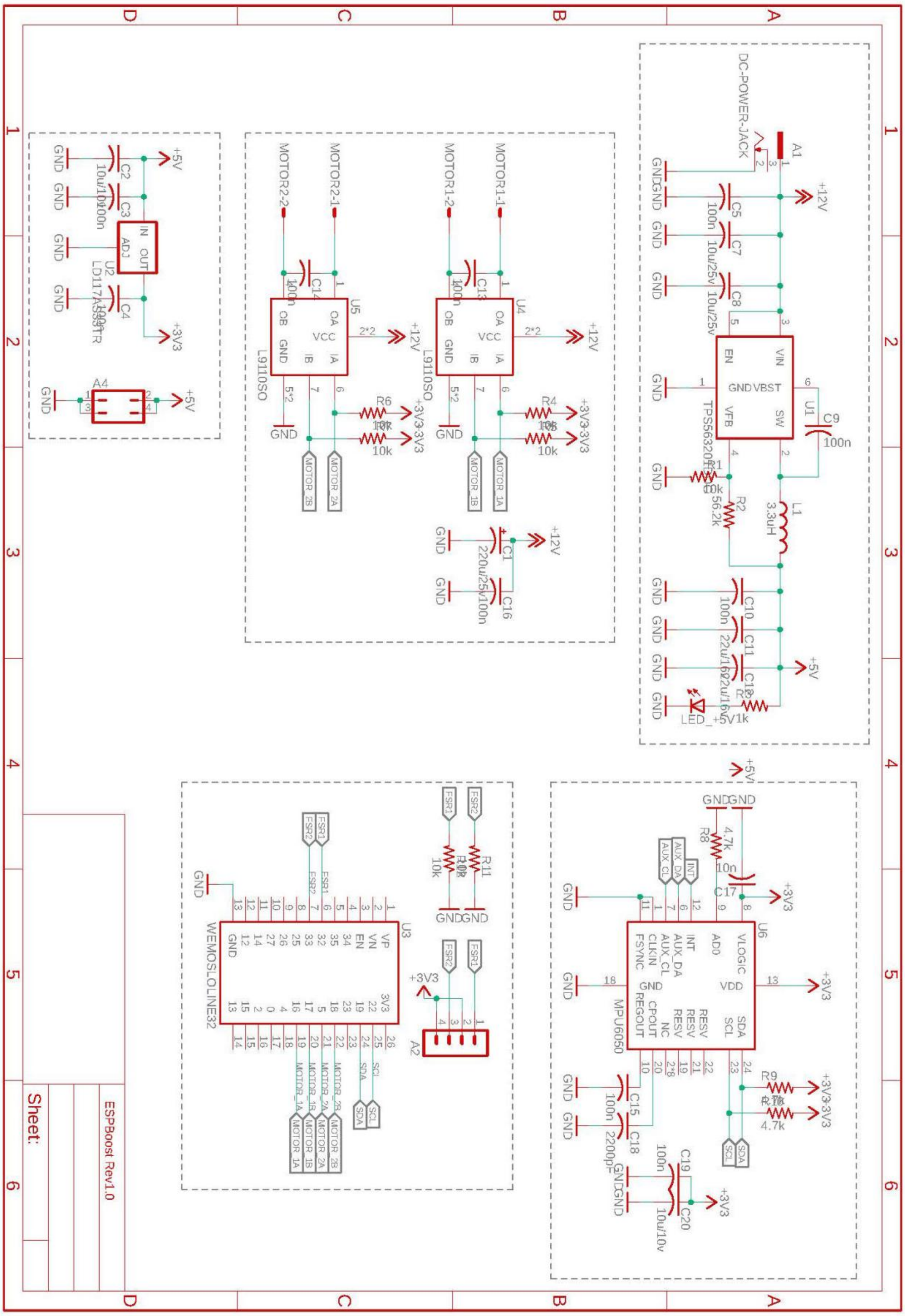
3) when exhaling, PneBall deflates;

Figure 34 The interaction with PneBall

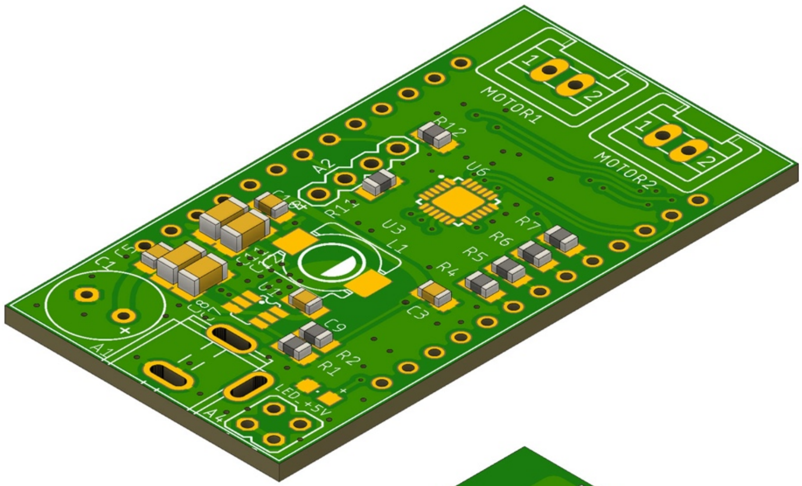
Appendix C: Wiring Diagram

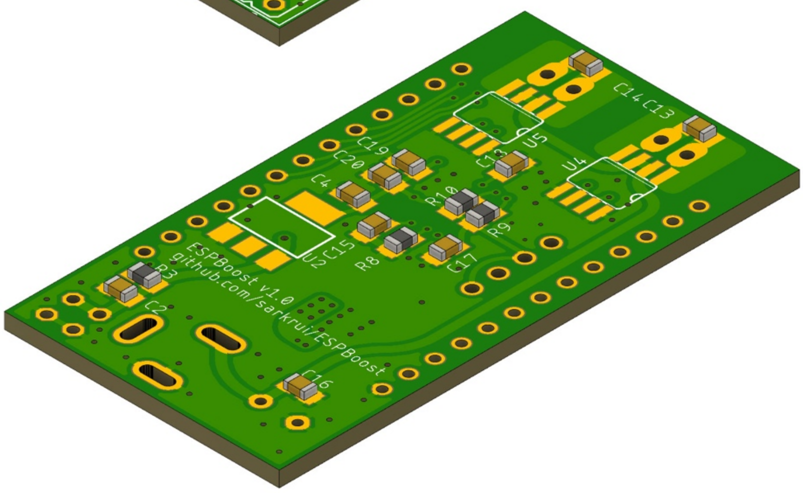


Appendix D: ESPBoost Schematic

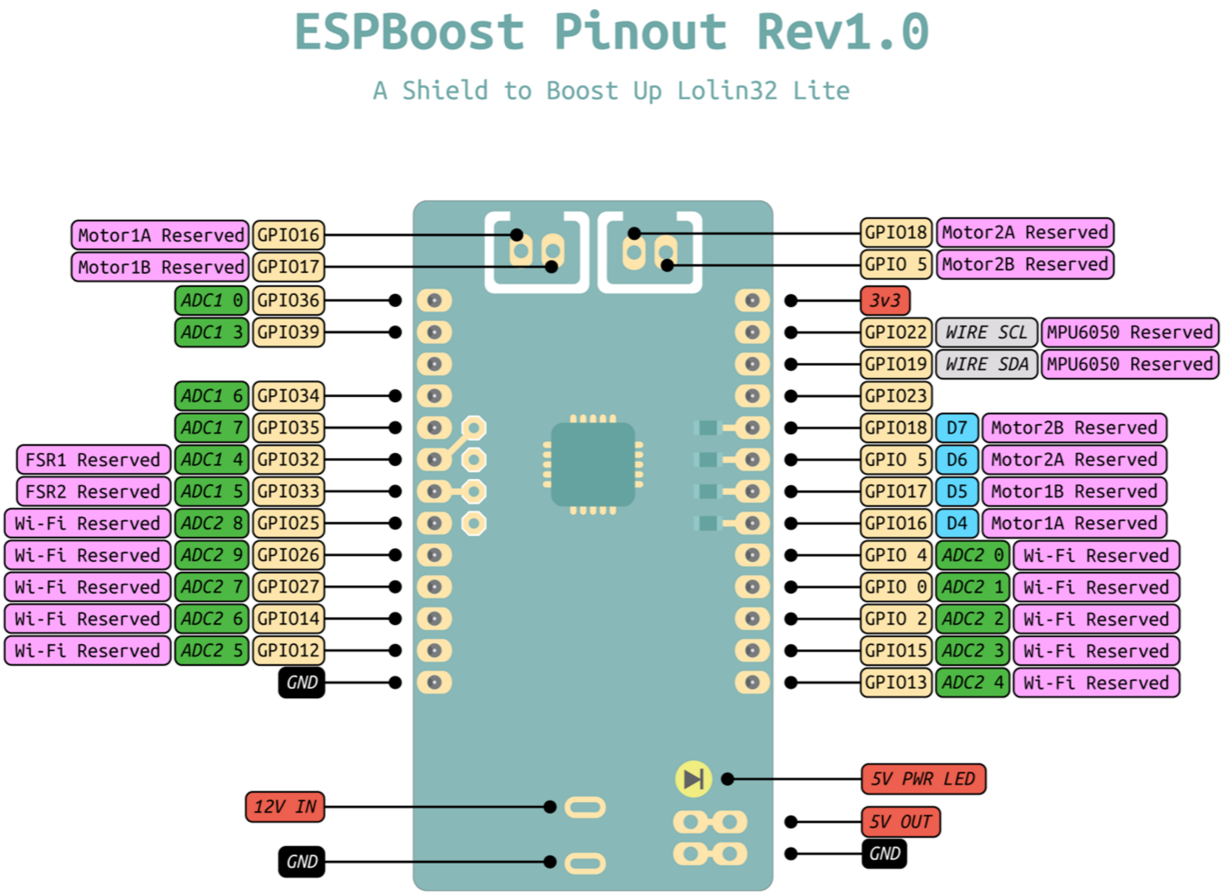


Appendix E: ESPBoost PCB





Appendix E: ESPBoost Pinout



Appendix F-1: Participant Recruitment Questionnaire[16]

IoTT Participants Recruitment

* Required

1. Email address *

GDPR Declaration

You are going to participate in an identifiable questionnaire. As we need to collect your contact information and to remain the compliance with General Data Protection Regulation (GDPR), hereby we would like to inform you how your privacy will be handled.

2. Taking part in the study *

Check all that apply.

- [ ] I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.
- [ ] I understand that taking part in the study my email address might be collected.

3. Use of the information *

Check all that apply.

- [ ] I understand that if my email address is collected, it will be stored securely on a private and encrypted Google Drive.
- [ ] I understand that my answers to the questions will be stored securely on a private and encrypted Google Drive.
- [ ] I understand that answers I provide might be used for presentations, publications, website anonymously.
- [ ] I understand that taking part in the study my email address might be collected.

4. Your right to the data *

Check all that apply.

- [ ] I understand I can request for the deletion of the collected data at any time.
- [ ] I understand I have the right to rectify any erroneous information at anytime.

Introduction

In this study, we would like to recruit participants who are interested in and skillful in developing Tangible Interactions. To achieve so, we create this enquiring form, where you will be going through 4 sections, answering up to 16 questions. It might take you up to 10 minutes to finish all the questions.

Quick Quiz!

Before we get into the prototyping challenge, we would like to learn about your general understandings of Tangible Interactions.

5. Do you know the exact difference between physical interactions and tangible interactions? *

Mark only one oval.

- Yes
- No
- Maybe

6. What does IoTT stand for? (yes, double T) * — 10 points

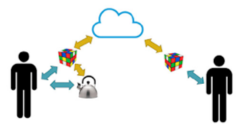


Figure 1. Interaction scenario for an IoTT system.

Please categorize the below designs by the type of interactions.

7. The Dangling String by Natalie Jeremijenko * — 1 point

A string that spins based on the information sent through the Ethernet cable

Mark only one oval.

- Tangible Interaction
- Physical Interaction
- Do not know the design or I cannot tell.

8. Move-it Sticky Notes * — 1 point

A mechanism to bench a sheet of paper or sticky notes to notify the user

Mark only one oval.

- Tangible Interaction
- Physical Interaction
- Do not know the design or I cannot tell.

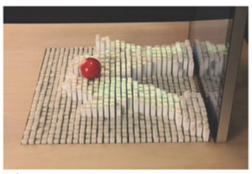
9. Generic PC Keyboard * — 1 point

Mark only one oval.

- Tangible Interaction
- Physical Interaction
- Do not know the design or I cannot tell.

10. The InForm by Daniel Leithinger * — 1 point

InForm shows how digital information (e.g. the hands captured by cameras) can be materialized to actuate other physical objects.



Mark only one oval.

- Tangible Interaction
- Physical Interaction
- Do not know the design or I cannot tell.

---

[16] IoTT Participant Recruitment Questionnaire available at https://links.pxing.design/iott

11. The Shape-changing Faucet * 1 point

Figure 2a-c: The Thrifty Faucet in different postures: Seeking, curious, and rejecting.

Mark only one oval.

- ⬭ Tangible Interaction
- ⬭ Physical Interaction
- ⬭ Do not know the design or I cannot tell.

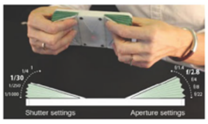
12. Generic PC Mouse * 1 point

Mark only one oval.

- ⬭ Tangible Interaction
- ⬭ Physical Interaction
- ⬭ Do not know the design or I cannot tell.

13. ReFlex * 1 point

A shape-changing interface for cameras, allowing shutter and aperture settings to be negotiated by forming or deforming the shape.



Mark only one oval.

- ⬭ Tangible Interaction
- ⬭ Physical Interaction
- ⬭ Do not know the design or I cannot tell.

14. Could you now briefly describe the differences between physical interactions and tangible interactions?
(Skip the question if you're not sure.)

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Prototyping with IoT

We would like learn more about your IoT prototyping experiences.

15. Have you ever used Lolin32 or other ESP variants? *

Mark only one oval.

- ⬭ Yes, I have used Lolin32 or Lolin-derivatives. *Skip to question 16*
- ⬭ No, but I have used other ESP MCUs (e.g. Nodemcu ESP32) *Skip to question 16*
- ⬭ No, but I have Arduino prototyping basics *Skip to question 18*
- ⬭ No, I have no rapid prototyping skills.

For ESP Exclusively

16. How would you usually drive a generic DC motor on an ESP? * 20 points

Mark only one oval.

- ⬭ I will wire it up directly from PWM digital ports.
- ⬭ I will Google suitable methods.
- ⬭ I have never thought about it.
- ⬭ It should be paired with certain driver modules.

17. How would you power up your ESP? *

Check all that apply.

- ☐ via +5V USB port (incl. Powerbank, PC, 5V adapter)
- ☐ via the built-in VIN with a 9V adapter
- ☐ with a 3.7V Rechargeable Li-Po Battery, charged by the on-board charger
- ☐ with an external power supply (e.g. 9V, 12V) and power regulating circuits
- Other: ☐ ______________________________

Prototyping Tasks

Imagine that you're going to develop a prototype that
- is portable to use
- is able to drive two DC motors (+5V@200mA)
- the motors can be controlled over the Internet to spin CW' or CCW'

How would you achieve so?

18. Choose which MCU you might use *

Mark only one oval.

- ⬭ Generic NodeMCU ESP8266/ESP32
- ⬭ Wemos Lolin32 or Lolin-derivatives
- ⬭ Wemos D1 mini
- ⬭ Arduino UNO (paired with an ESP module)
- ⬭ Adafruit ESP32/8266 Feather
- ⬭ Other: ______________________________

19. Choose which actuator and related peripherals you might need *

Mark only one oval.

- DRV8833 H-Bridge
- L9110s H-Bridge
- Arduino UNO Shield
- FireBeetle Covers
- NodeMCU Motor Shield
- D1 mini Motor Shield
- I don't think I will need them.
- Other: ______________________

20. How would you power up your prototype? *

Choose the scenario that fit you best

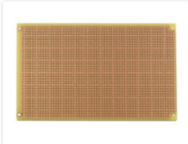
Mark only one oval.

- I will power the components up individually. (e.g. ESP via a USB cable, motors via a 9V battery)
- I will power it with a 3.7V Rechargeable Li-Po Battery and charge it with some techniques.
- I will develop a centralized power supply and I will google it how to achieve so.
- I will design a power adapting circuit for it.
- Uh, I have no idea.
- Other: ______________________

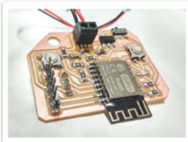
21. How would you wire up your electronic components?

Mark only one oval.

- Breadboard



- Padboard



- Custom PCB board
- I don't use any boards.
- Other: ____________

22. Choose the platform you would build your project on? *

Mark only one oval.

- Firebase Realtime Database by Google
- OOCSI (OOCSImote, OOCSI-ESP) by Mathias Funk
- MQTT-based Server
- I don't know.
- Other: ______________________

Lastly

23. Have you ever encountered any other difficulties in developing IoT prototypes? Preferably when tangible interactions were involved.

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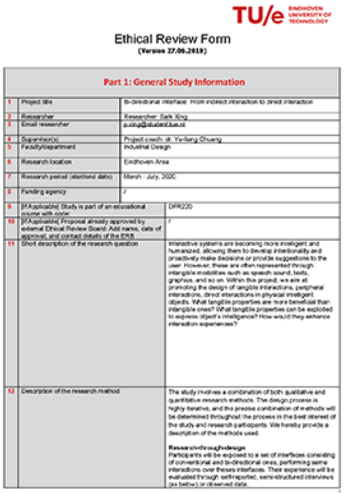
Appendix F-2: Table of analysis

P#	Score	Good?	Do you know the exact difference between physical interactions and tangible interactions?	What does IoTT stand for? (yes, double T)	The Dangling String by Natalie Jeremijenko	Move-it Sticky Notes	The InForm by Daniel Leithinger
P1	2 / 37		No	Internet of technology things	Physical Interaction	Physical Interaction	Physical Interaction
P2	7 / 37		Maybe	Internet of Trusted Things, so the cube means some kind of protocol I guess.	Tangible Interaction	Tangible Interaction	Tangible Interaction
P3	5 / 37		Yes	yes	Physical Interaction	Tangible Interaction	Tangible Interaction
P4	6 / 37		Yes	Internet of tangible things?	Tangible Interaction	Tangible Interaction	Tangible Interaction
P5	2 / 37		Maybe	the things in this system not only can interact with each with internet, but also with LAN ?	Do not know the design or I cannot tell.	Do not know the design or I cannot tell.	Tangible Interaction
P6	15 / 37		Maybe	Internet of Tangible Things	Do not know the design or I cannot tell.	Physical Interaction	Tangible Interaction
P7	34 / 37		Yes	Internet of Tangible Things	Do not know the design or I cannot tell.	Tangible Interaction	Tangible Interaction
P8	21 / 37		Maybe	Internet of Trusted Things	Physical Interaction	Physical Interaction	Physical Interaction
P9	5 / 37		No	N/A	Tangible Interaction	Tangible Interaction	Physical Interaction

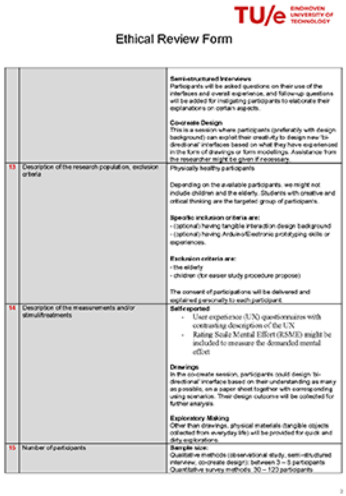
P#	The Shape-changing Faucet	ReFlex	Generic PC Mouse	Generic PC Keyboard	Could you now briefly describe the differences between physical interactions and tangible interactions?	Have you ever used Lolin32 or other ESP variants?	How would you usually drive a generic DC motor on an ESP?
P1	Tangible Interaction	Tangible Interaction	Tangible Interaction	Tangible Interaction	Tangible interaction required the user to touch the object/design to interact. Physical interaction include a physical design to let the user do something but not touching the design.	No, but I have Arduino prototyping basics	
P2	Tangible Interaction	Tangible Interaction	Physical Interaction	Physical Interaction		No, but I have used other ESP MCUs (e.g. Nodemcu ESP32)	I will wire it up directly from PWM digital ports.
P3	Physical Interaction	Tangible Interaction	Physical Interaction	Physical Interaction	interact with information or not	Yes, I have used Lolin32 or Lolin-derivatives.	I will Google suitable methods.
P4	Do not know the design or I cannot tell.	Tangible Interaction	Physical Interaction	Physical Interaction	Tangible interaction usually involves shape changing? And the changing of shape indicates some information or invites some actions?	Yes, I have used Lolin32 or Lolin-derivatives.	I have never thought about it.
P5	Tangible Interaction	Physical Interaction	Tangible Interaction	Tangible Interaction	Tangible interaction: people interact with certain system with their body motion input, the user input will be processed by computer, then transfer to be output. Physical interaction: people interact with certain physical object without the processing by computer.	No, but I have Arduino prototyping basics	
P6	Tangible Interaction	Tangible Interaction	Physical Interaction	Physical Interaction	Tangible interactions involve users' operations in the int]raction. On the contrary, physical interactions refer to the change of artifacts in their physical forms.	No, but I have Arduino prototyping basics	
P7	Tangible Interaction	Tangible Interaction	Tangible Interaction	Tangible Interaction	I am not sure anymore, I thought tangible interaction is something to do with changing / shaping a product. Something you feel or touch and can change it. Physical interaction is more static?	No, but I have used other ESP MCUs (e.g. Nodemcu ESP32)	It should be paired with certain driver modules.
P8	Do not know the design or I cannot tell.	Tangible Interaction	Tangible Interaction	Tangible Interaction	I'm not completely sure. During tangible interactions, users are able to interact with a digital (ungraspable) world using physical objects. I think that physical interactions happen more frequently as an information provider (system provides information to user) than receiver (user provides information to system). In the latter of the two, the user is not necessarily able to provide information to the system.	Yes, I have used Lolin32 or Lolin-derivatives.	It should be paired with certain driver modules.
P9	Physical Interaction	Tangible Interaction	Physical Interaction	Physical Interaction		No, I have no rapid prototyping skills.	

P#	How would you power up your ESP?	Choose which MCU you might use	Choose which actuator and related peripherals you might need	How would you power up your prototype?	How would you wire up your electronic components?	Choose the platform you would build your project on?	Have you ever encountered any other difficulties in developing IoT prototypes? Preferably when tangible interactions were involved.
P1		Arduino UNO (paired with an ESP module)	I don't think I will need them.	Uh, I have no idea.	Breadboard	I don't know.	Not been in touched with ioT prototypes
P2	via +5V USB port (incl. Powerbank, PC, 5V adapter), with a 3.7V Rechargeable Li-Po Battery, charged by the on-board charger	Generic NodeMCU ESP8266/ESP32	NodeMCU Motor Shield	I will usually power them up individually. (e.g. ESP via a USB cable, motors via a 9V battery)	Padboard	OOCSI (OOCSImote, OOCSI-ESP) by Mathias Funk	Sometimes the delay of GET and POST data from a database/server is uncontrollable, and it may destroy the consistency between IoT devices
P3	via +5V USB port (incl. Powerbank, PC, 5V adapter), with a 3.7V Rechargeable Li-Po Battery, charged by the on-board charger	Generic NodeMCU ESP8266/ESP32	D1 mini Motor Shield	I will usually power them up individually. (e.g. ESP via a USB cable, motors via a 9V battery)	Padboard	OOCSI (OOCSImote, OOCSI-ESP) by Mathias Funk	
P4	via +5V USB port (incl. Powerbank, PC, 5V adapter), with a 3.7V Rechargeable Li-Po Battery, charged by the on-board charger	Wemos Lolin32 or Lolin-derivatives	D1 mini Motor Shield	I will power the components up individually. (e.g. ESP via a USB cable, motors via a 9V battery)	Breadboard	Firebase Realtime Database by Google, OOCSI (OOCSImote, OOCSI-ESP) by Mathias Funk	So many that I can't even tell :?
P5		Arduino UNO (paired with an ESP module)	L9110s H-Bridge	I will develop a centralized power supply and I will google it how to achieve so.	Breadboard	OOCSI (OOCSImote, OOCSI-ESP) by Mathias Funk	the electronic element in one circuit should be adapted to each other. There are many combination schemes but I have to determinedI can access to all the elements and all of them would be worked well, or I should try other scheme.
P6		Arduino UNO (paired with an ESP module)	D1 mini Motor Shield	I will power it with a 3.7V Rechargeable Li-Po Battery and charge it with some techniques.	Breadboard	OOCSI (OOCSImote, OOCSI-ESP) by Mathias Funk	Not sure how to answer.
P7	via +5V USB port (incl. Powerbank, PC, 5V adapter)	Adafruit ESP32/8266 Feather	L9110s H-Bridge	I will design a power adapting circuit for it.	Breadboard	OOCSI (OOCSImote, OOCSI-ESP) by Mathias Funk	Yes, IoT prototypes but not tangible interactions. The difficulties were mostly connecting/configuring it with the OOCSI. But eventually when it worked, I also have experienced delay in getting data so the prototype would response late. Sometimes hardware problems for example breaking
P8	depends on the use case (and specifics of the DC motor)	Wemos D1 mini	D1 mini Motor Shield	I will power it with a 3.7V Rechargeable Li-Po Battery and charge it with some techniques.	Padboard	Depends on the use case of the prototype. But for a user test / prototyping scenario i would probably go with an existing platform such as Blynk.	Yes. For tangible interactions i think my main concern and/or experienced problem would regard the vulnerability of (low/mid fidelity) prototypes that need to be physically interacted with. As the objects need to be physically altered to allow for the interaction, a lot of vulnerable components come in to play to allow for the change in shape/movement.
P9							

Appendix G: Ethical Review Form

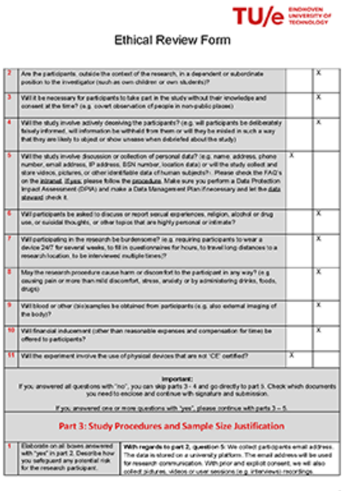

Ethical Review Form
(Version 27.06.2019)

Part 1: General Study Information

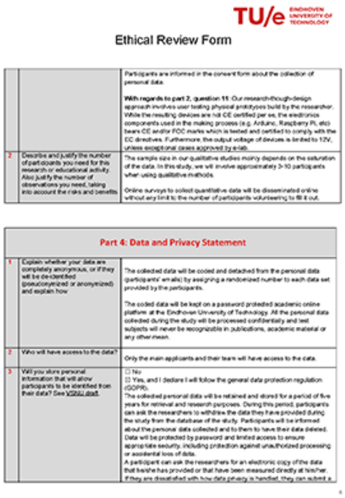

Ethical Review Form


Ethical Review Form

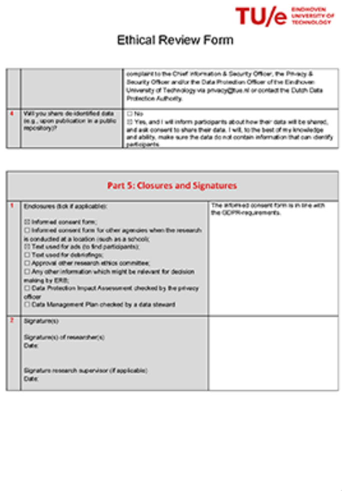
Part 2: Checklist for Minimal Risk


Ethical Review Form

Part 3: Study Procedures and Sample Size Justification


Ethical Review Form

Part 4: Data and Privacy Statement


Ethical Review Form

Part 5: Closures and Signatures

Appendix H: Informed Consent Form

Researchers: Sark Xing **Project:** DFR220 – Final Master Project (FMP) **Supervisor:** Ya-liang Chuang

Description of the research

You are invited to participate in an user study for a student project at the TU/e. In this study, we are going to test the interactions of an interface designed for light (or music) controll. The results might be used for presentation and graduation report. During the study, you will be given with a laptop as well as interfaces which are used to control the light blub next to you or music streming service. You are free to browse films on Netflix, Music, etc. as well as to play with the interface. After that, you can reflect on your experience and understandings in semi-structured interview with audio recording. Lastly, under the researcher's assistance, you will go through a quick and dirty session where you explore design possibilites with some tangible objects from everyday life. The researcher might take photos during the study at any time. Please feel free to ask questions whenever you encounter questions.

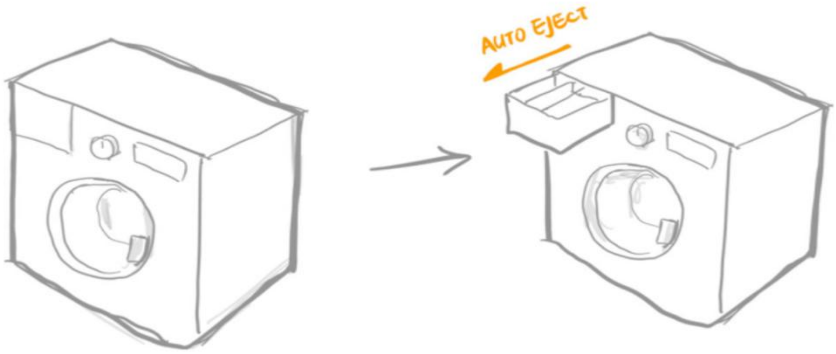
Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [DD/MM/YYYY], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
I understand that taking part in the study involves: *an audio-recorded interview, photos taken by the researcher.*	☐	☐
Use of the information in the study		
I understand that information I provide might be used for *presentations, publications, website* anonymously.	☐	☐
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	☐	☐
I agree that my sayings can be trascribed and quoted in research output.	☐	☐

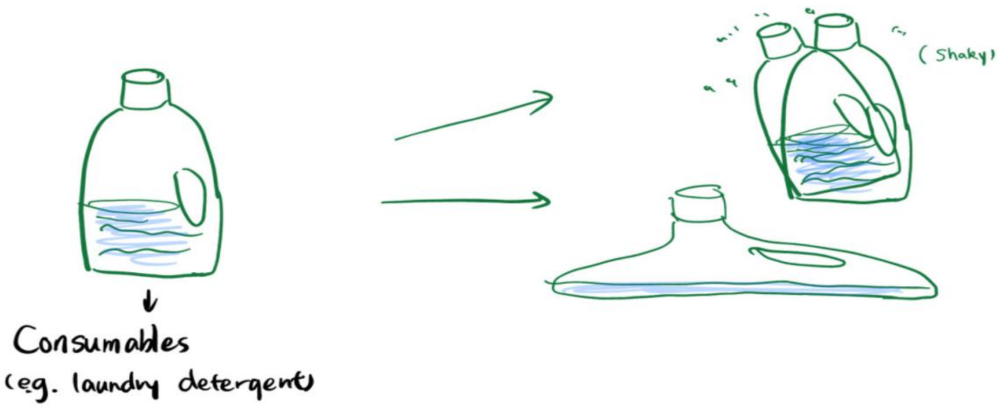
Signatures

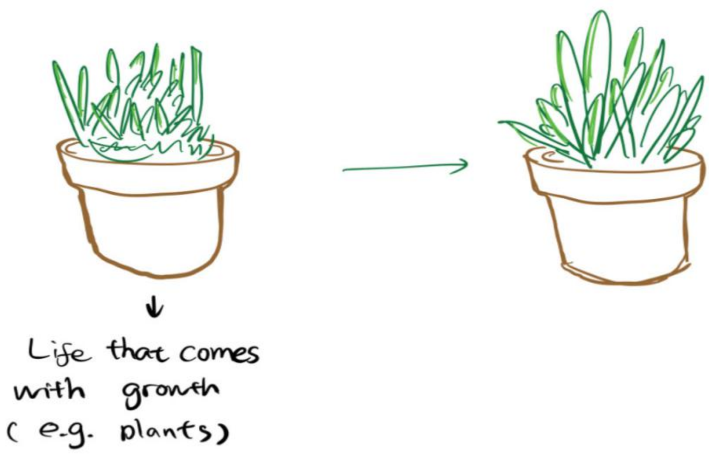
________________________ ________________________ __________

Name of participant Signature Date

Appendix I: Results of the pilot study







Appendix J-1: Arduino Code Topplr Control

```
//MPU6050 Gyro
#include <MPU6050_tockn.h>
#include <Wire.h>
MPU6050 mpu6050(Wire);
float   preAngleX,   preAngleY,   preAngleZ,
nowAngleX, nowAngleY, nowAngleZ, diffX, diffY,
diffZ;

//BLE KeyBoard
#include <BleKeyboard.h>
BleKeyboard bleKeyboard;
#define volumeThreshold 10
#define trackThreshold 18
#define debounce 60

void setup() {
  Serial.begin(115200);
  Wire.begin(19, 22);
  mpu6050.begin();
  mpu6050.setGyroOffsets(-2.66, -1.40, 1.75);

  bleKeyboard.begin();
}

void motionDetect() {

  preAngleX = nowAngleX;
  preAngleY = nowAngleY;
  preAngleZ = nowAngleZ;
  mpu6050.update();
  nowAngleX = mpu6050.getAngleX();
  nowAngleY = mpu6050.getAngleY();
  nowAngleZ = mpu6050.getAngleZ();
  //1 enabled; 0 disabled
  MPU6050log(1);
  delay(debounce);
}

void loop() {
  motionDetect();
  exeFunctions();
}
void exeFunctions() {
  if (bleKeyboard.isConnected()) {
    if  (diffX  >  trackThreshold  ||  diffY  >
trackThreshold) {

      Serial.println("Sending    Media    Next
Track");
      bleKeyboard.write(KEY_MEDIA_NEXT_TRACK);
    }

    if (diffX < -trackThreshold || diffY < -
trackThreshold) {
      Serial.println("Sending  Media  Previous
Track");

bleKeyboard.write(KEY_MEDIA_PREVIOUS_TRACK);
    }

    if (diffZ > volumeThreshold) {

      bleKeyboard.write(KEY_MEDIA_VOLUME_UP);
      Serial.println("Sending    Media    Volume
Up");
    }

    if (diffZ < -volumeThreshold) {

      bleKeyboard.write(KEY_MEDIA_VOLUME_DOWN);
      Serial.println("Sending    Media    Volume
Down");
    }
  }
}
void MPU6050log(boolean logState) {

  if (logState == true) {
    Serial.print("\t");
    Serial.print(diffX = nowAngleX - preAngleX);
    Serial.print("\t");
    Serial.print(diffY = nowAngleY - preAngleY);
    Serial.print("\t");
    Serial.println(diffZ    =    nowAngleZ    -
preAngleZ);
  }
  else {}
}
```

Appendix J-2: Arduino Code Topplr Output

```
//DC Motor
#define motorP D2
#define motorN D3

void setup() {
  Serial.begin(115200);
  pinMode(motorP, OUTPUT);
  pinMode(motorN, OUTPUT);
}

void loop() {
  digitalWrite(motorP, HIGH);
  digitalWrite(motorN, LOW);
  delay(10);
  digitalWrite(motorN, LOW);
  digitalWrite(motorP, LOW);
  delay(1000);
  digitalWrite(motorP, LOW);
  digitalWrite(motorN, HIGH);
  delay(10);
  digitalWrite(motorN, LOW);
  digitalWrite(motorP, LOW);
  delay(1000);

}
```

Appendix K: Related links

- Portfolio link: https://pxing.design
- ESPBoost Project Link: https://links.pxing.design/ESPBoost
- IoTT Participant Recruitment Questionnaire link: https://links.pxing.design/iott
- Breathe-in Project link: https://ddwtue.nl/breathe-in/
- [HELP] How to post an HTTP with headers? · Issue #3483 · espressif/ arduino-esp32. GitHub. Retrieved February 13, 2020 from https://github. com/espressif/arduino-esp32/issues/3483
- HELP json.set() adds a "null" on which the code doesn't designate · Issue #68 · mobizt/Firebase-ESP8266. GitHub. Retrieved February 13, 2020 from https://github.com/mobizt/Firebase-ESP8266/issues/68
- FirebaseJson returns invalid values from non-existent nodes · Issue #85 · mobizt/Firebase-ESP8266. GitHub. Retrieved February 13, 2020 from https://github.com/mobizt/Firebase-ESP8266/issues/85
- HELP FSR402 doesn't work with Firebase-ESP32 · Issue #40 · mobizt/ Firebase-ESP32. GitHub. Retrieved February 13, 2020 from https://github. com/mobizt/Firebase-ESP32/issues/40
- L9110 2-Channel Motor Control Driver Chip. Retrieved June 8, 2020 from https://www.elecrow.com/download/datasheet-l9110.pdf